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MULTIPLE SEISMIC EVENTS

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Wisconsin University

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15 July 1974

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Second Semiannual Technical Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

P-wave amplitude spectra in the range of 1.0 to 0.135 Hz were found to have negative mean slopes for two NTS nuclear shots and a mean slope of zero for the Massachusetts Mountain earthquake of 5 August 1971. Auto- and cross-correlations were made at first zone distances for nuclear shots and earthquakes which originated in the same general source region and were recorded at the same stations. Cross-correlations between different nuclear shots produced significantly higher cross-correlations than between shots and

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earthquakes. Cepstrum analysis techniques were applied to nuclear and earthquake recordings but the results to date are insufficient to yield firm conclusions due to the limited data base. Seismicity studies of the Nevada Test Site area disclosed an overall decline in seismic activity for the time period 1 June 1969 through 31 March 1973. The first three months of 1973 disclosed an increase in seismicity by a factor of approximately three over the preceding time period of approximately two years. During the latter period there was an average of approximately 4.5 earthquakes per week with an average strain release of 15.5 x 10^6 ergs$^{1/2}$. Surface and body wave magnitude radiation patterns were determined for six NTS events and three Amchitka shots. Anomalous patterns were observed on the North American continent.

Technical Report Summary

This is the second semiannual report dealing with an investigation of multiple seismic events and first zone discriminants. Spectral analyses were made for several nuclear shots and an earthquake that had the same general transmission paths between source region and recording stations. The results of these studies showed that the mean slope of the nuclear event spectra in the frequency range from 1.0 to 0.135 Hz is negative, while the mean slope for the earthquake over the same frequency range is zero. Similar analysis for additional events is currently underway.

Cross-correlation studies were initiated between different nuclear shots recorded at the same stations and between an earthquake and nuclear shots for the same stations. This approach allows the utilization of phase information that would normally be lost in spectral studies. The data analyzed in this manner show a significantly higher correlation between different nuclear shots recorded at the same station than between nuclear shots and earthquakes. Further analysis of this type is in progress. Attempts to obtain additional earthquake data from the NTS source region or other pairs of earthquake/nuclear recordings will be made.

The study of secondary arrivals by use of Cepstrum analyses was continued during this report period. Theoretical P-wave arrival delays for vertically separated and horizontally separated sources were computed as well as the effect of azimuthal variations in the delays for horizontally separated events. The technique was applied for a nuclear event and an earthquake recorded at the same set of stations. The results were insufficient to yield firm conclusions because of the limited data base. Additional studies along these lines are currently in progress.

A FORTRAN program was obtained from NOAA that will allow the determination of station coverage on detection potential of given sized events. This program is being modified for operation with the UNIVAC 1110 at the University of Wisconsin and will be used in conjunction with the concept of unmanned observatories to determine detection thresholds and required spatial distributions.

Seismicity studies of the Nevada Test Site area were undertaken in order to determine the perturbation of the natural seismicity due to the testing program. An overall decline in seismic activity was determined for the 200-week time period 1 June 1969 through 31 March 1973 although the last three months or so of this time period showed an increase in activity that did not appear to be shot related. During the 200-week period, two large shots, JORUM and HANDLEY, were followed by larger than average earthquake activity, both in total numbers per week and in strain release. The seismicity returned to apparent normal levels approximately 20 weeks following HANDLEY. Over an approximate 100-week time interval where the shot activity did not appear to influence significantly the pattern of earthquake activity, an average of 4.5 earthquakes occurred each week with an accompanying accumulative strain release of 15.5×10^6 $\text{ergs}^{1/2}$ per week.

Surface and body wave magnitude radiation patterns were determined for six of the larger NTS events and for the three nuclear shots fired at Amchitka. Larger magnitude anomalies were found in the eastern United States and Canada. However, in the Basin and Range Province and the southern Pacific Border Province, a large negative residual was observed for M_s magnitudes. The same area had a small positive residual for the m_b magnitudes.

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July 15, 1974

AFOSR Grant No. 73-2543	Report No. 144-E123-6-T
Investigation of Multiple Seismic Events and First Zone Discriminants	Effective Date of Grant 1 June 1973
	Grant Expiration 31 May 1975
ARPA Order No. 1827	$94,470
Program Code 3F10	Project Scientists: R. W. Taylor
The University of Wisconsin-Milwaukee	and D. E. Willis

Air Force Office of Scientific Research
ATTN: NPG
1400 Wilson Boulevard
Arlington, Virginia 22204

Subject: Second Semiannual Technical Report for Period Covering 1 January 1974 through 31 May 1974.

Dear Sir:

This report is a summary of research dealing with multiple seismic events and first zone discriminants. The research is divided into the following categories and will be discussed individually.

Introduction

This report covers the second six-month period of an investigation into the design of discriminants to detect and identify multiple seismic sources from natural earthquakes recorded at first zone distances with particular emphasis on utilizing unmanned observatories. The study includes both theoretical and analytical investigations.

During this report period, most of the useable seismic data obtained previously were digitized and the analyses continued. The latter includes the determination of the spectral content, radiation patterns, corner frequency, seismic moment and stress drop. Cepstrum analysis techniques are being used to study the geometrical dependent time delays in the body waves caused by the physical separation of the multiple events and the delays caused by slap down and pP. The spatial distribution of unmanned observatories, their magnification and effects of background noise are also being investigated.

Technical Reports, Publications and Presentations

During this report period a paper entitled "Earth Strain Measurements and Strain Release in Nevada and Adjacent Areas" was presented at the 69th Annual Meeting of the Seismological Society of America on 31 March 1974 at Las Vegas, Nevada.

The following graduate student theses, which were sponsored in part by this grant, were also completed during this report period:

Tatar, Philip J., Analysis of South-Central Nevada Earth Strain Measurements and the Potential Influence of Earth Tides on Microearthquakes Recorded at Groom Mine, Nevada

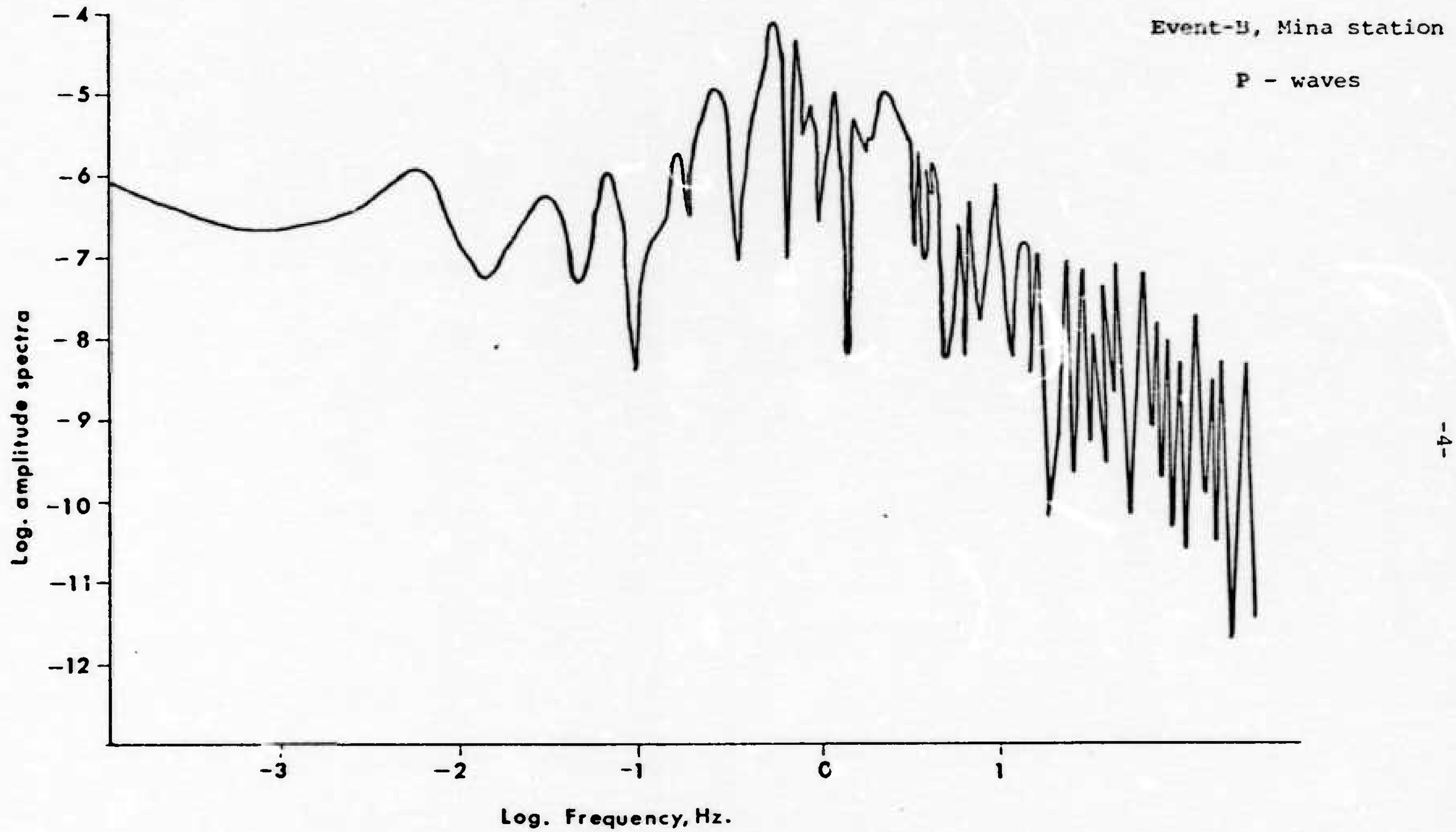
George, Gary D., Investigation of Spatial and Temporal Migration of Seismic Activity in the California/Nevada Area

P-Wave Amplitude Spectra

A comparison of P-wave amplitude spectra for nuclear and natural seismic events was initiated. At present only the Massachusetts Mountain earthquake of August 5, 1971 (an m_b 4.2 event located at approximately 36°48"N, 115°57"W) has been employed as a representative natural event. Since this earthquake was located sufficiently close to actual test sites, corrections for any differential travel paths were felt to be unnecessary. Corrections for the differences in event magnitudes were not made since corrections of this nature would not lend themselves to unmanned observatories.

The present results of these studies are shown in Figures 1 through 7 . It is evident from these figures that the mean slope of the nuclear event spectra in the frequency range from 1 Hz to .135 Hz is negative, while the mean slope of the spectra for the Massachusetts Mountain earthquake in the same frequency range is zero. This is in accordance with the observations of Wyss et al. (1971). Additional nuclear events are presently being analyzed and it is intended that additional earthquakes will be included.

The identification logic for an unmanned observatory, utilizing the difference in spectral slope indicated by Figures 1 through 7, is outlined in Figure 8 . Figure 8 is intended as a procedural outline and does not include the logic necessary for detection and windowing of the arriving wave-train. It will also be noted that the detection logic is not specifically designed for the detection of multiple events but rather for the detection of underground explosions. To invalidate the logic, however, would require suppression of the event spectra in the region of 0.5 Hz. This would require horizontal event separations on the order of 5 km or firing delays on the order of 1 sec.


Event-B, Mina station
P - waves
-4
-5
-6
-7
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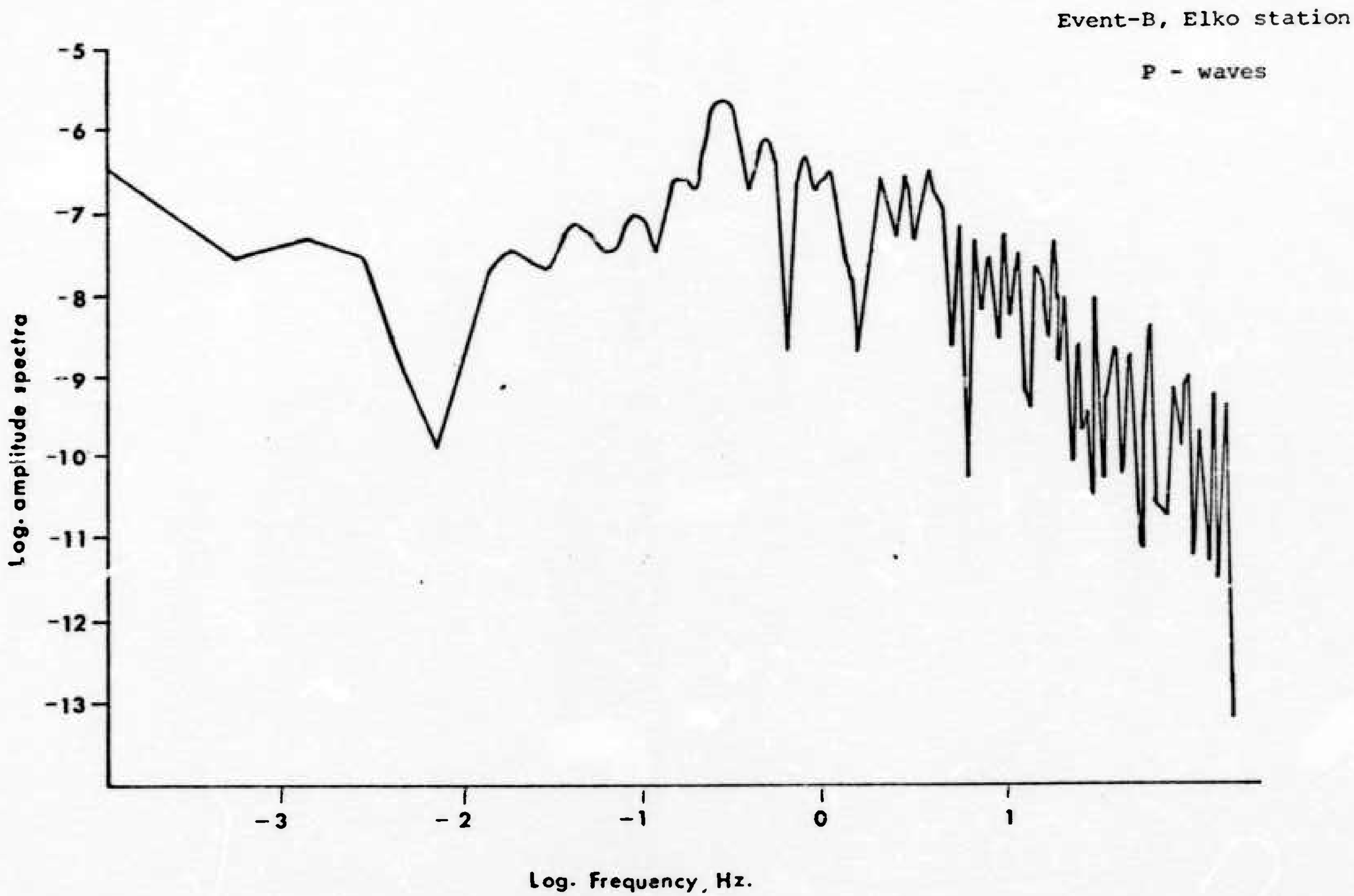
-9
-10
-11
-12
Log. amplitude spectra
-3
-2
-1
0
1
Log. Frequency, Hz.

Figure 1


Event-B, Elko station
P - waves
Log. amplitude spectra
-5
-6
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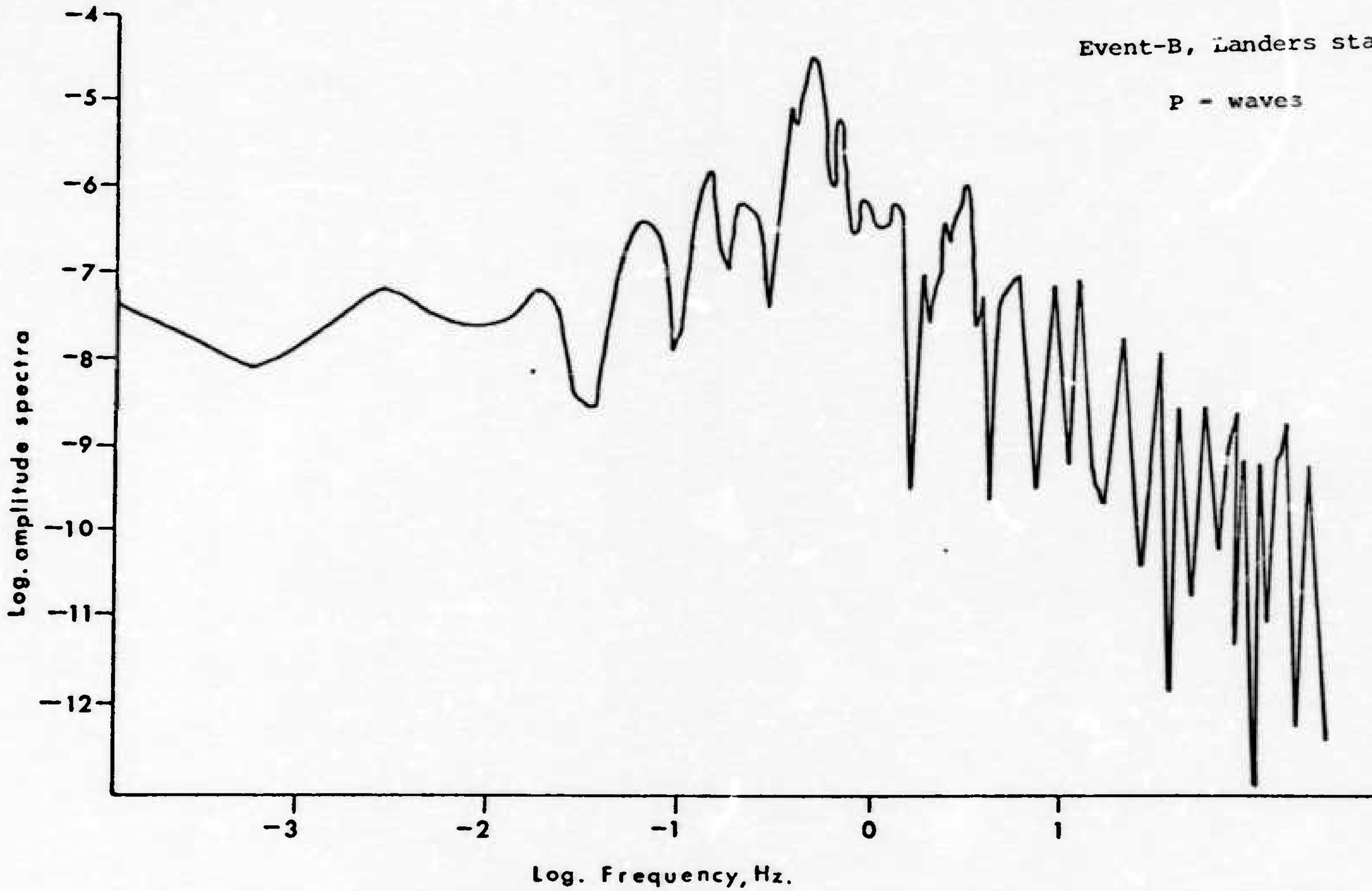
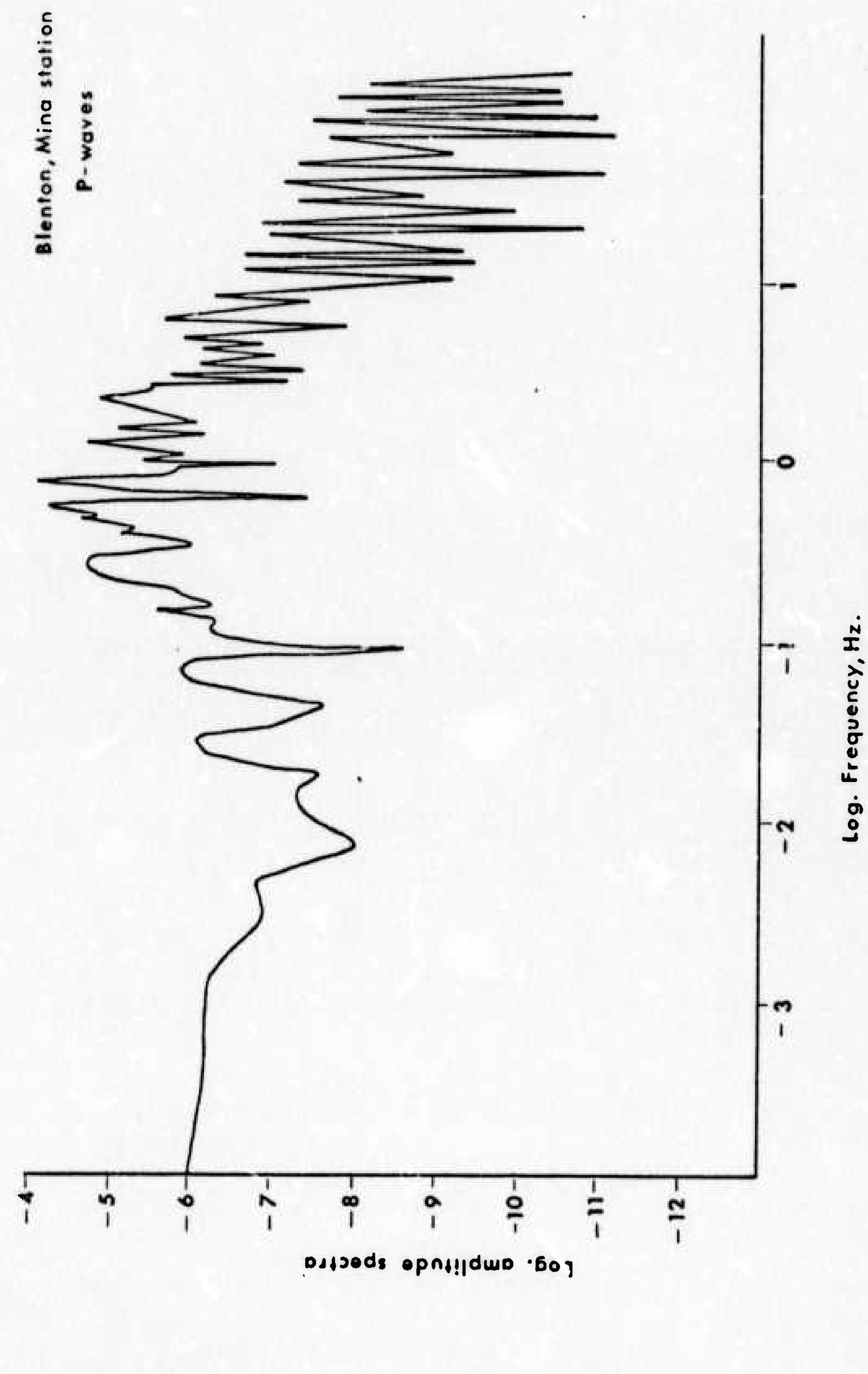
1
Log. Frequency, Hz.

Figure 2



Event-B, Landers station
P - waves
Log. amplitude spectra
-4
-5
-6
-7
-8
-9
-10
-11
-12
-3
-2
-1
0
1
Log. Frequency, Hz.

Figure 3


Blenton, Mina station
P-waves
-4
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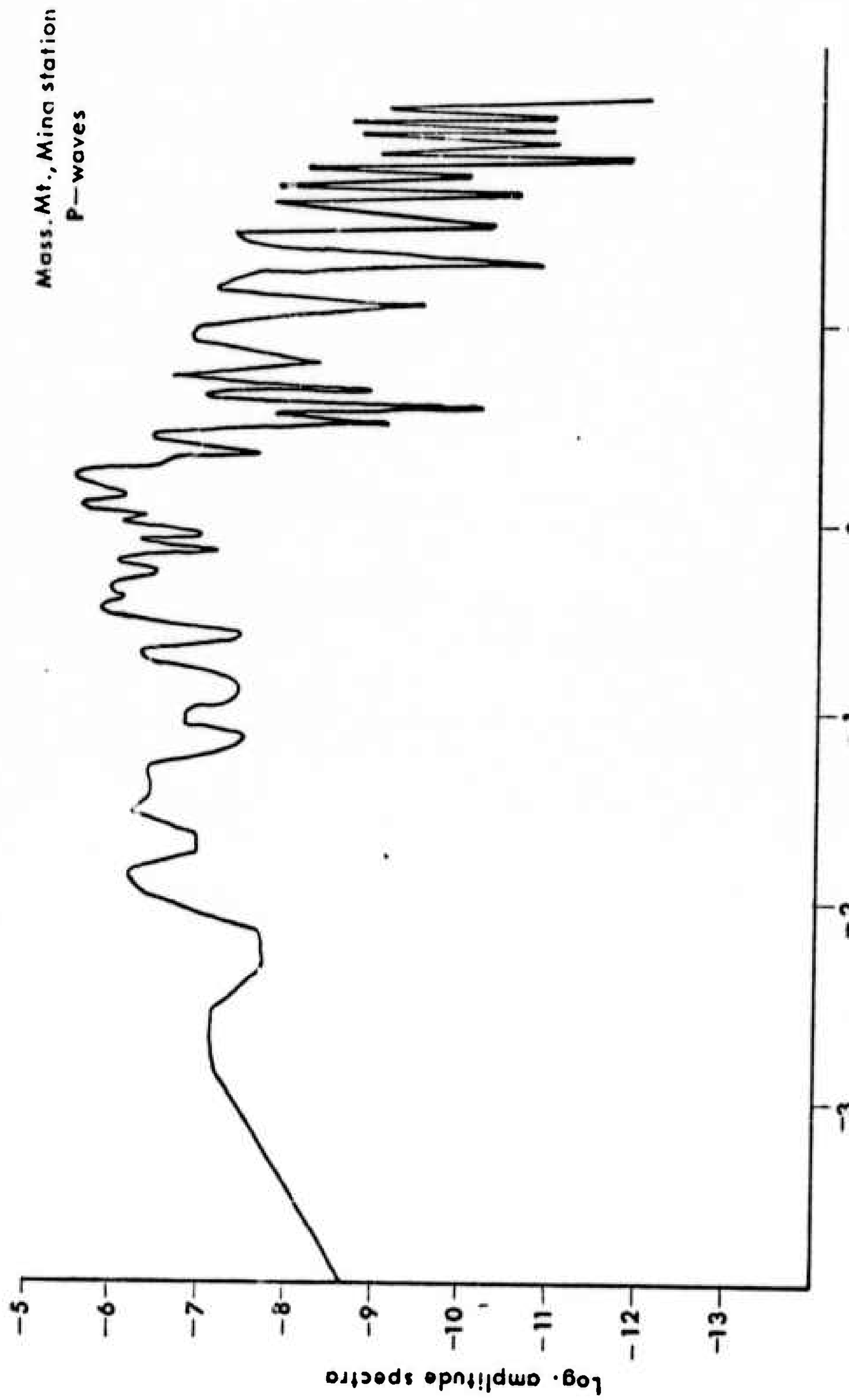
-12
Log. amplitude spectra
-3
-2
-1
0
1
Log. Frequency, Hz.

Figure 4


Mass. Mt., Mina station
P—waves
Log. amplitude spectra
-5
-6
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-3
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-1
0
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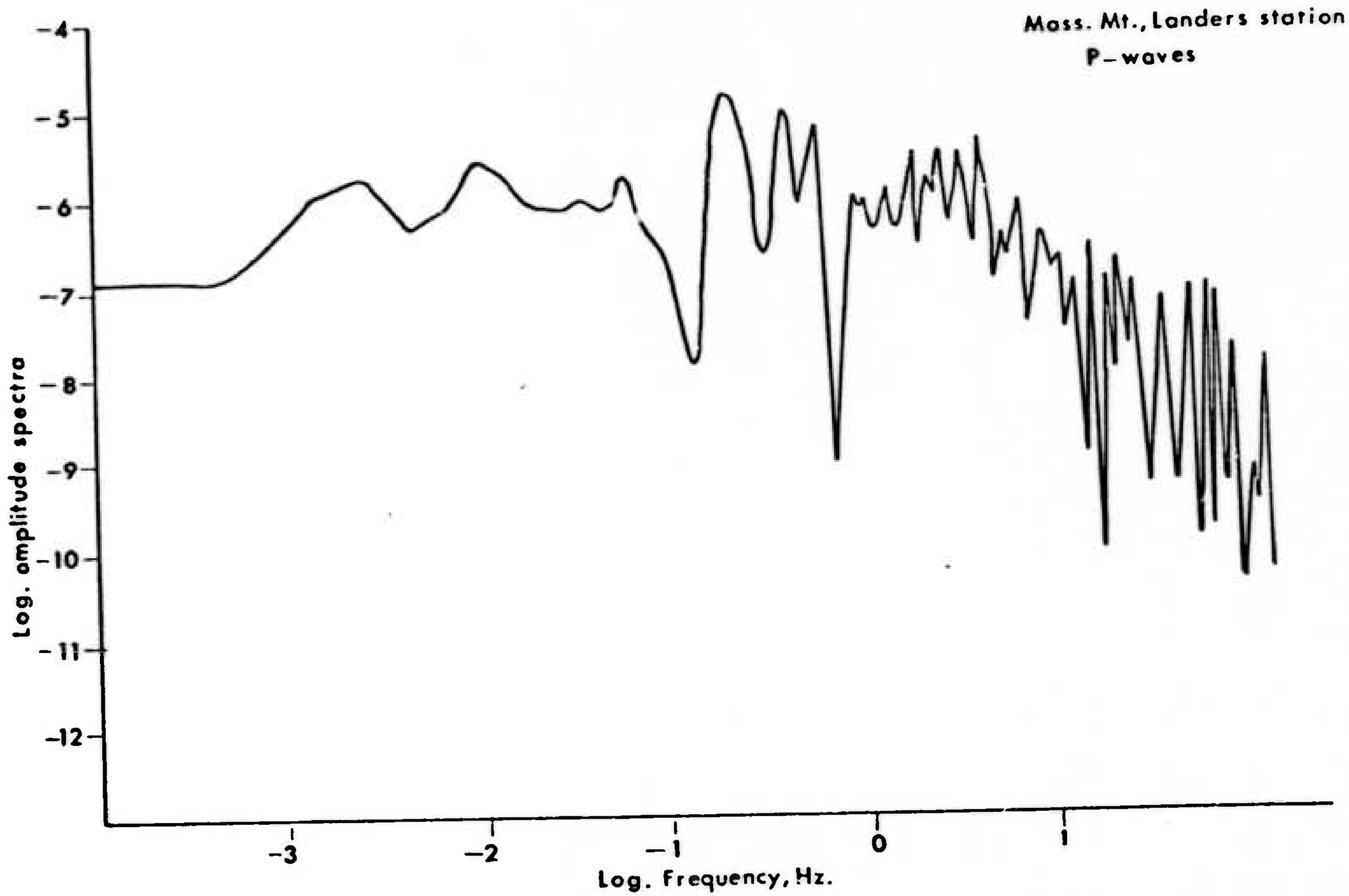
Log. Frequency, Hz.

Figure 5


Mass. Mt., Landers station
P—waves
Log. amplitude spectra
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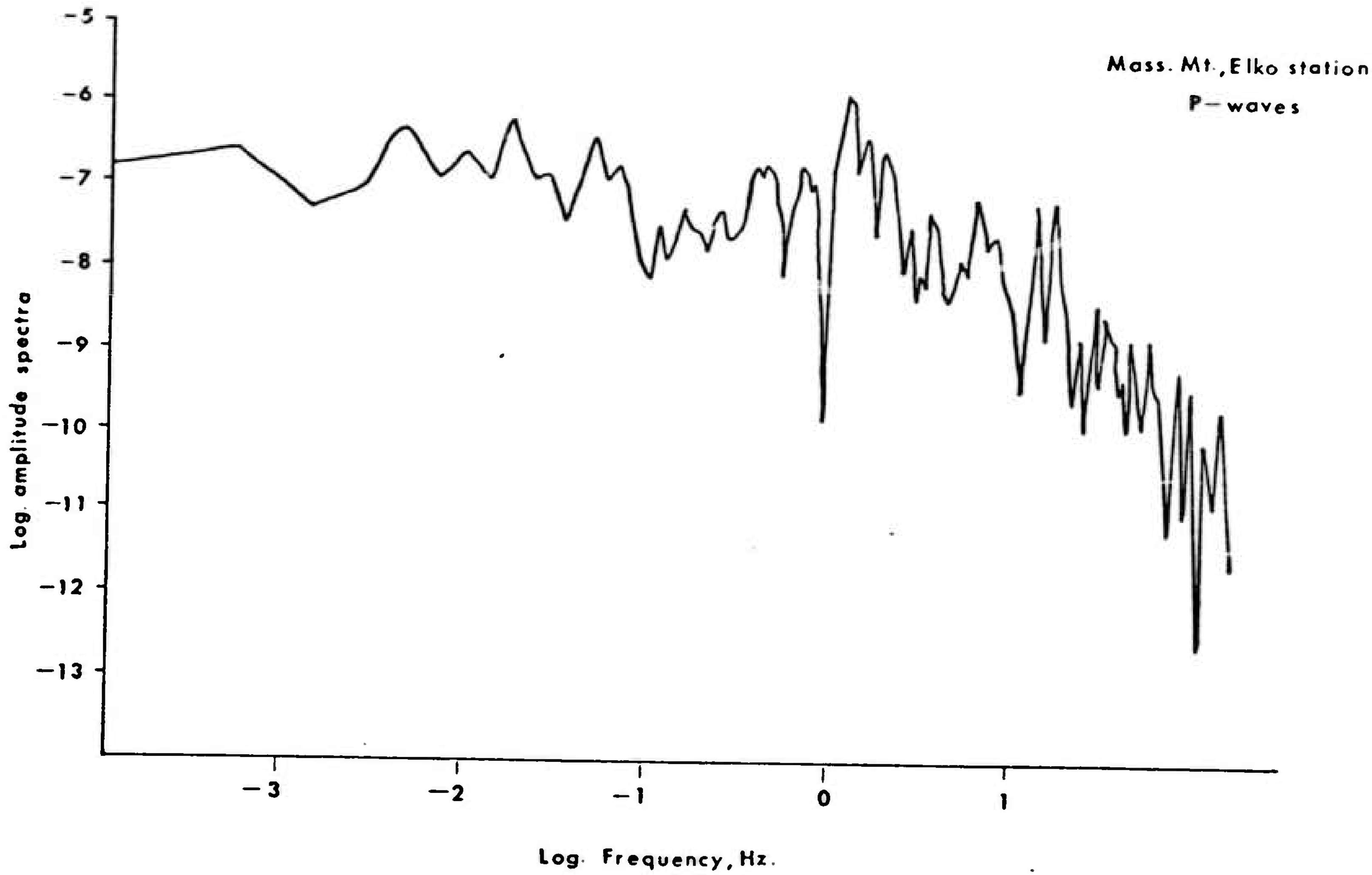
0
1
Log. Frequency, Hz.

Figure 6


Mass. Mt., Elko station
P—waves
Log. amplitude spectra
Log. Frequency, Hz.
-5
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-12
-13
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-2
-1
0
1

Figure 7

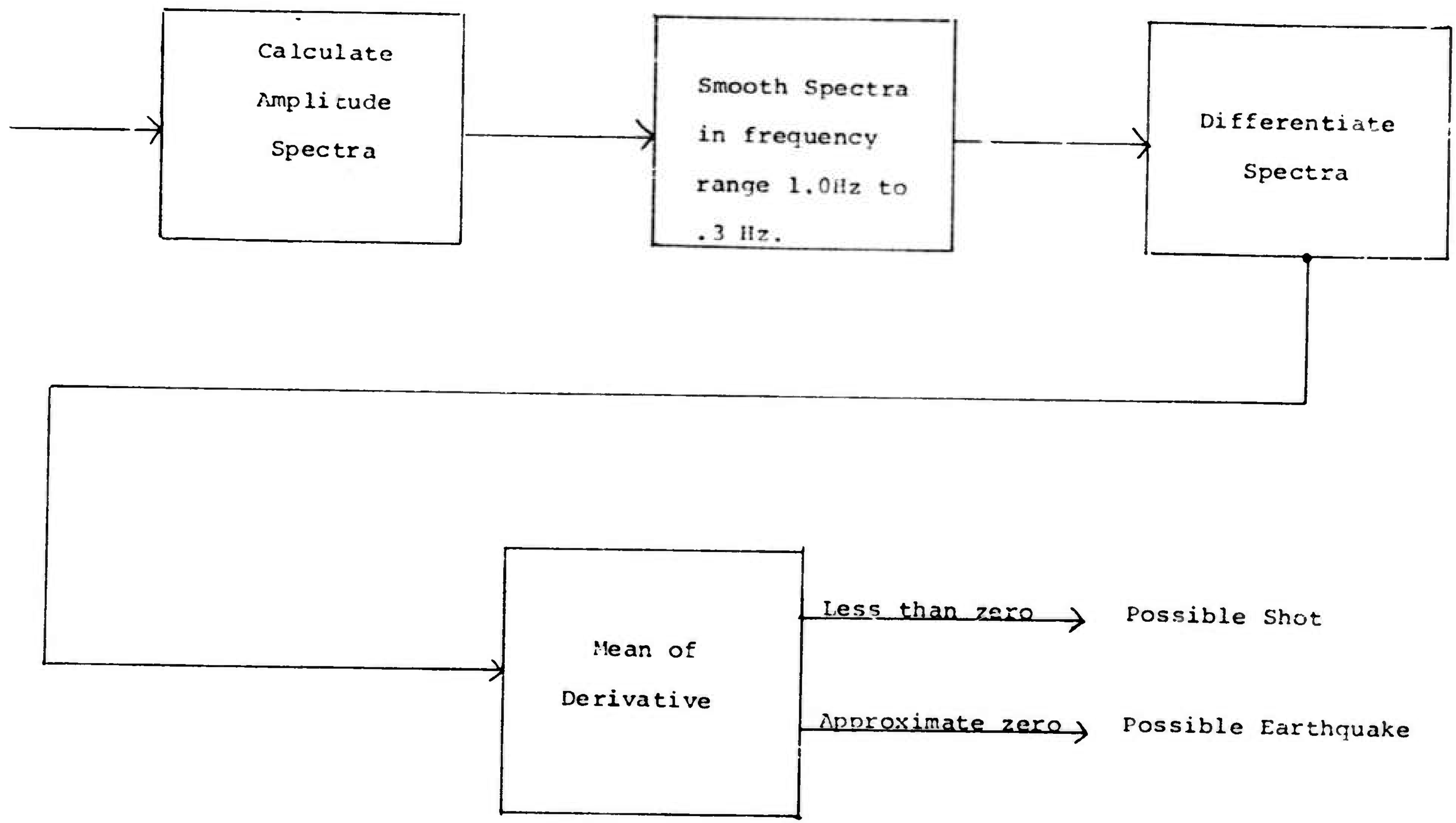


Figure 8

Identification logic, based on slope of the P-wave amplitude spectra, for an unmanned observatory.

Cross-Correlation Methods

Fourier amplitude studies suffer from a failure to utilize the phase information contained in the record and appear to limit detection logic to selected pass bands. Cross-correlation methods provide a potential means for utilizing phase information and the entire pass-band of the record. In view of the increased utilization of information contained in the records, cross-correlation studies were initiated.

Typical auto-correlations for a nuclear event and natural earthquake are shown in Figures 9 and 10. These auto-correlations are intended for reference only and the evident differences have received no consideration. The cross-correlation of two nuclear events, Event-B and BLENTON, is shown in Figure 11. The peak value of approximately 0.8 at zero lag in this figure is of particular interest. The cross-correlation of an earthquake and nuclear event, Massachusetts Mountain and Event-B, as seen at two stations is shown in Figures 12 and 13. A significant difference in the cross-correlations is evident from a comparison of Figures 11, 12 and 13. The decrease in peak value of the correlation to approximately 0.3 is particularly significant in view of the peak value of 0.8 obtained with similar events (Figure 11).

While the above correlation results are limited in number, they suggest a potential identification logic outlined in Figure 14. In essence, the identification logic is to employ the waveform resulting from a known source as a match filter for the record from an unknown source. The peak output of match filter is then used to indicate identification. Increased confidence and decreased false alarms may be obtained by the use of additional known waveforms.

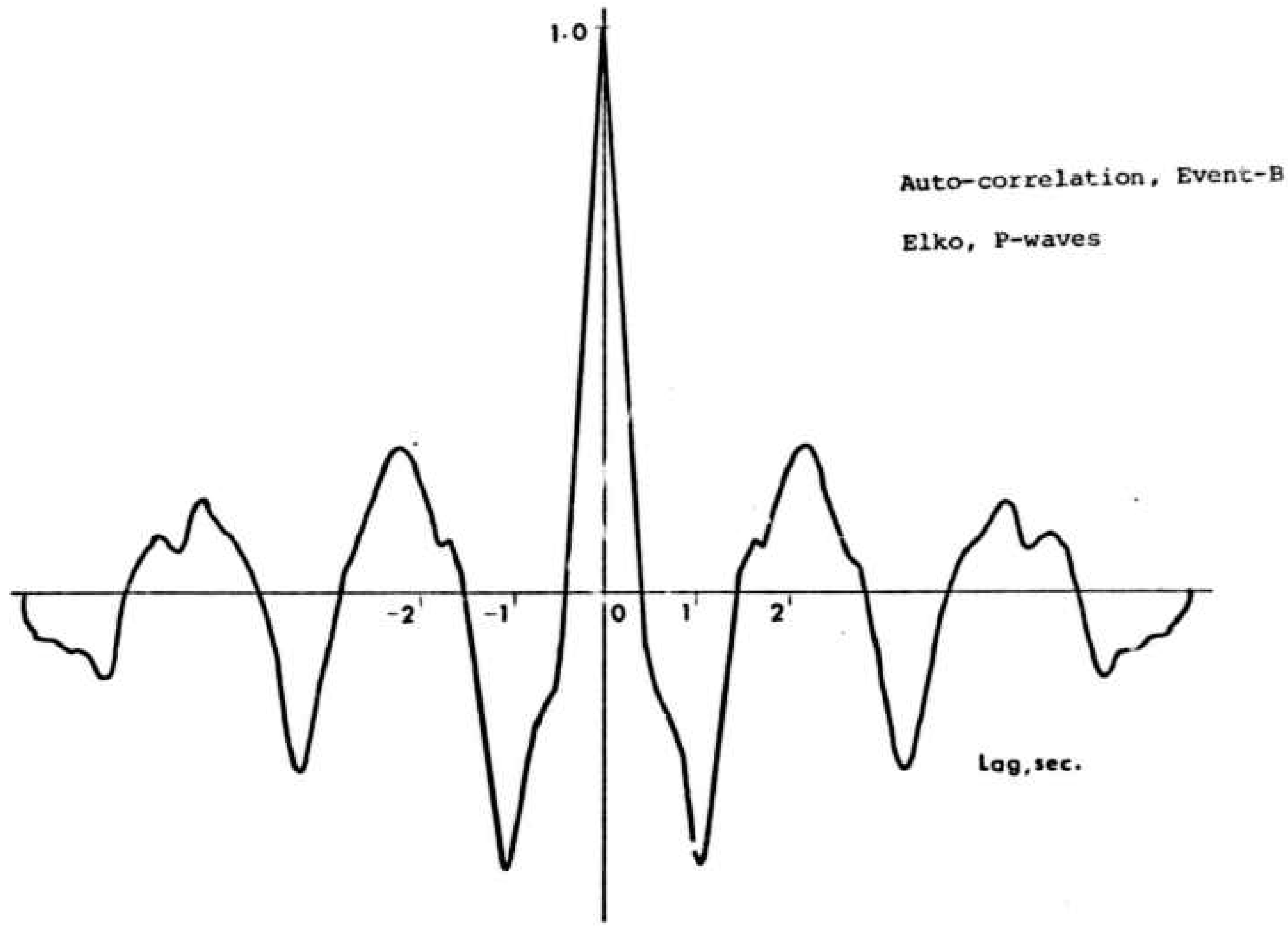


Figure 9. Auto-correlation of P-wave arrival for nuclear event.

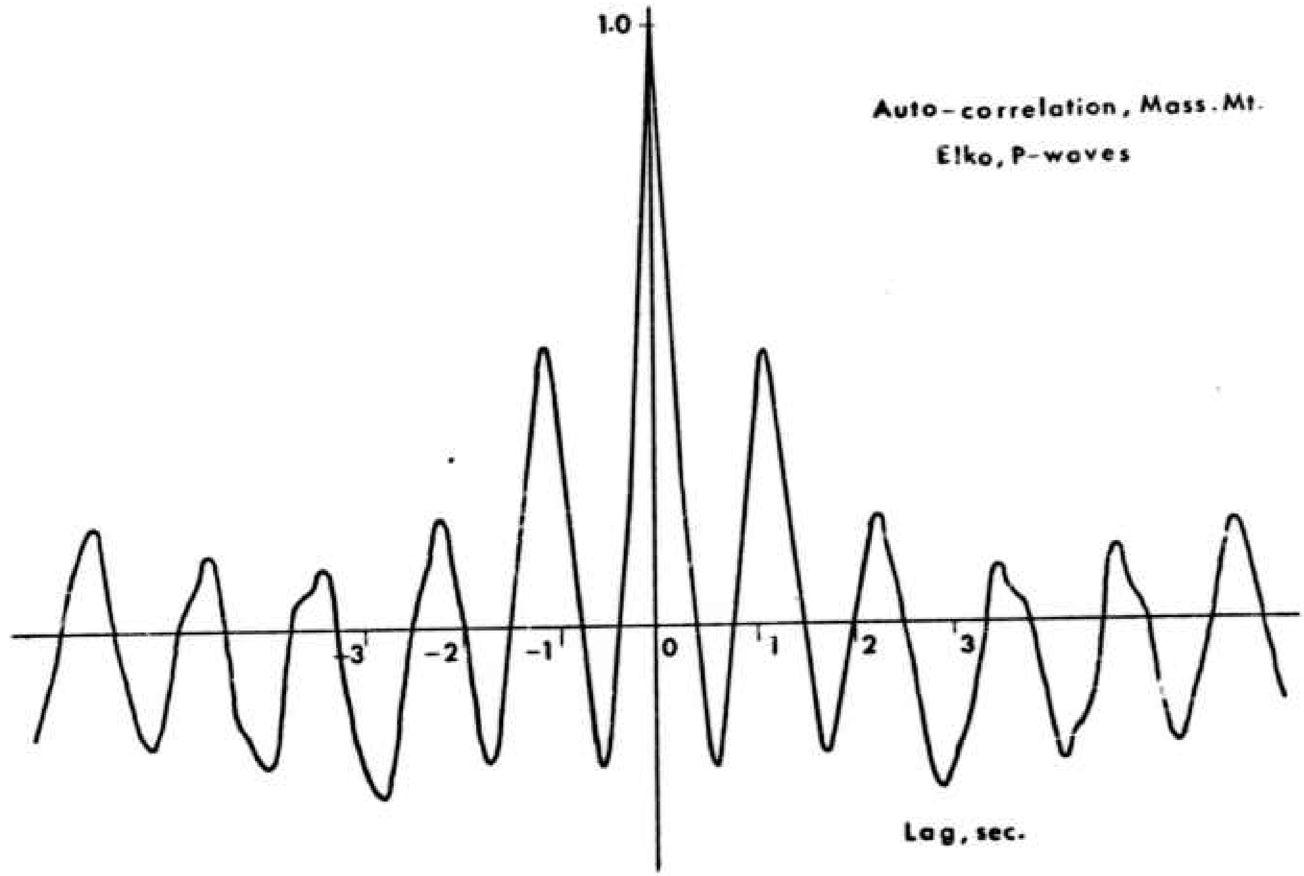


Figure 10

Auto-correlation of P-wave arrival for a natural event.

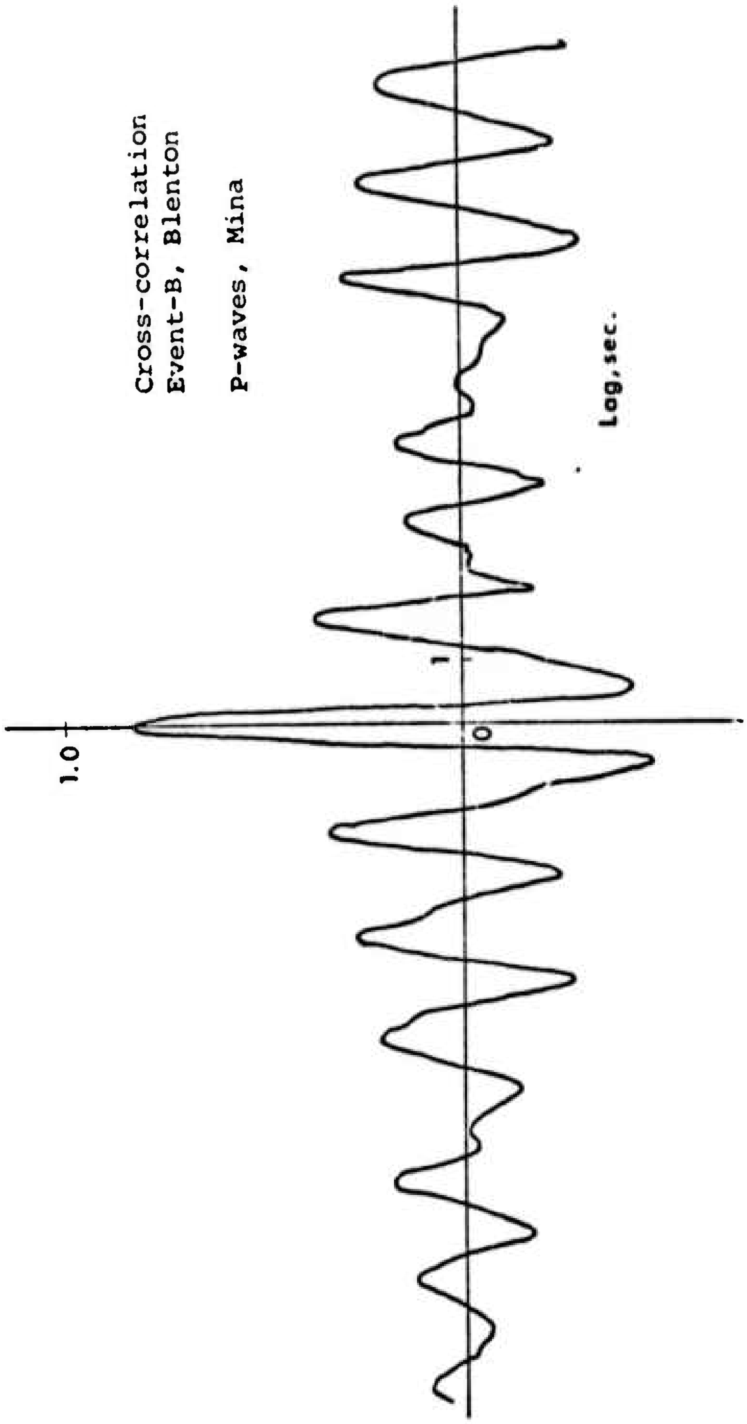


Figure 11

Cross-correlation for two nuclear events

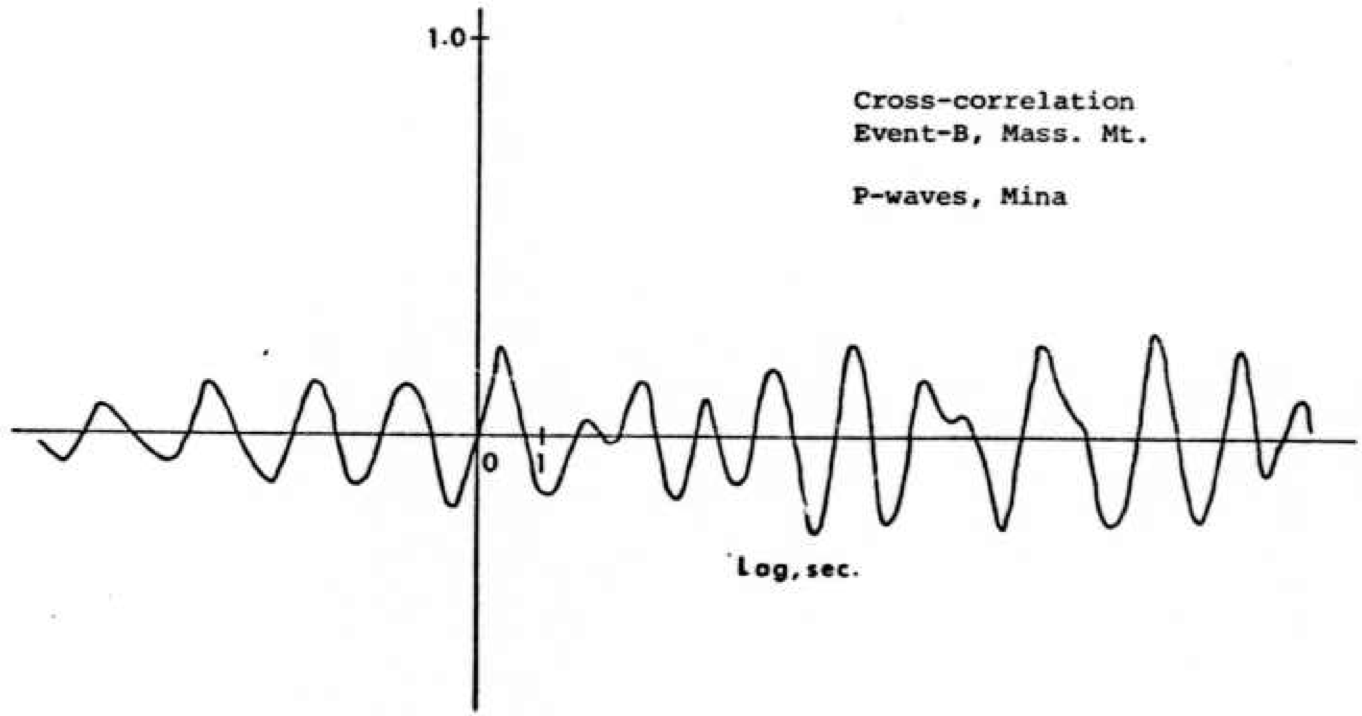


Figure 12

Cross-correlation of P-wave arrivals from a nuclear shot and natural event.

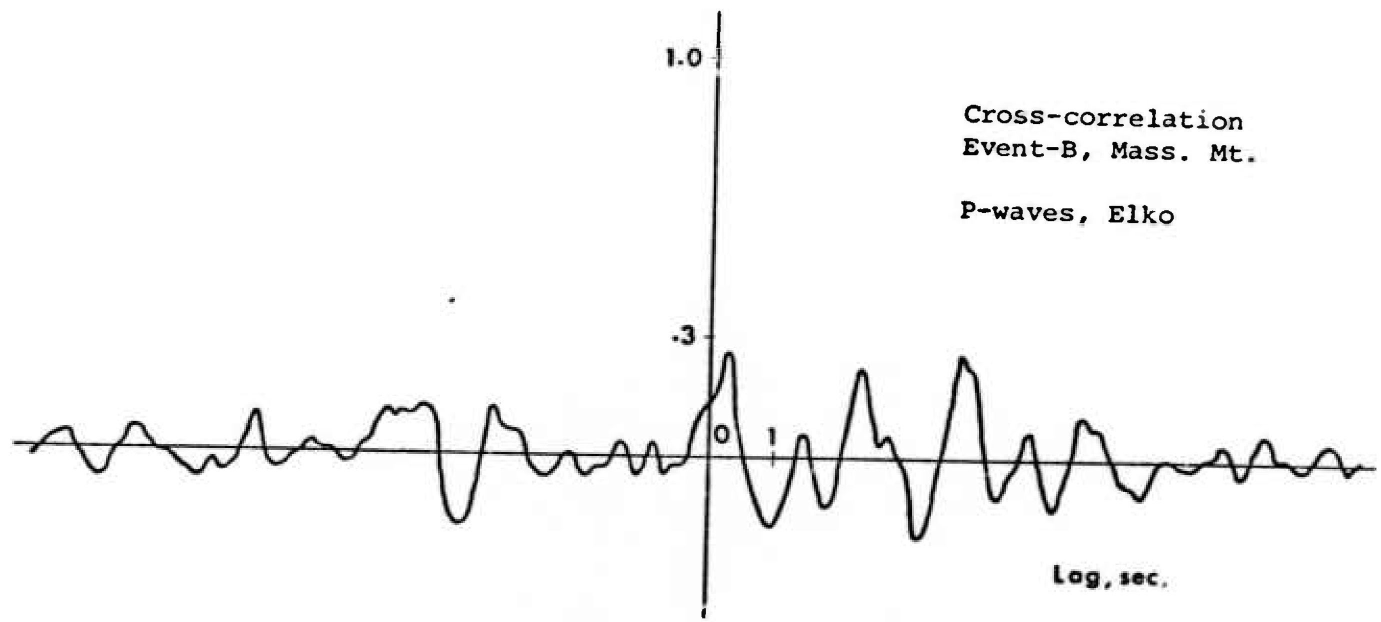
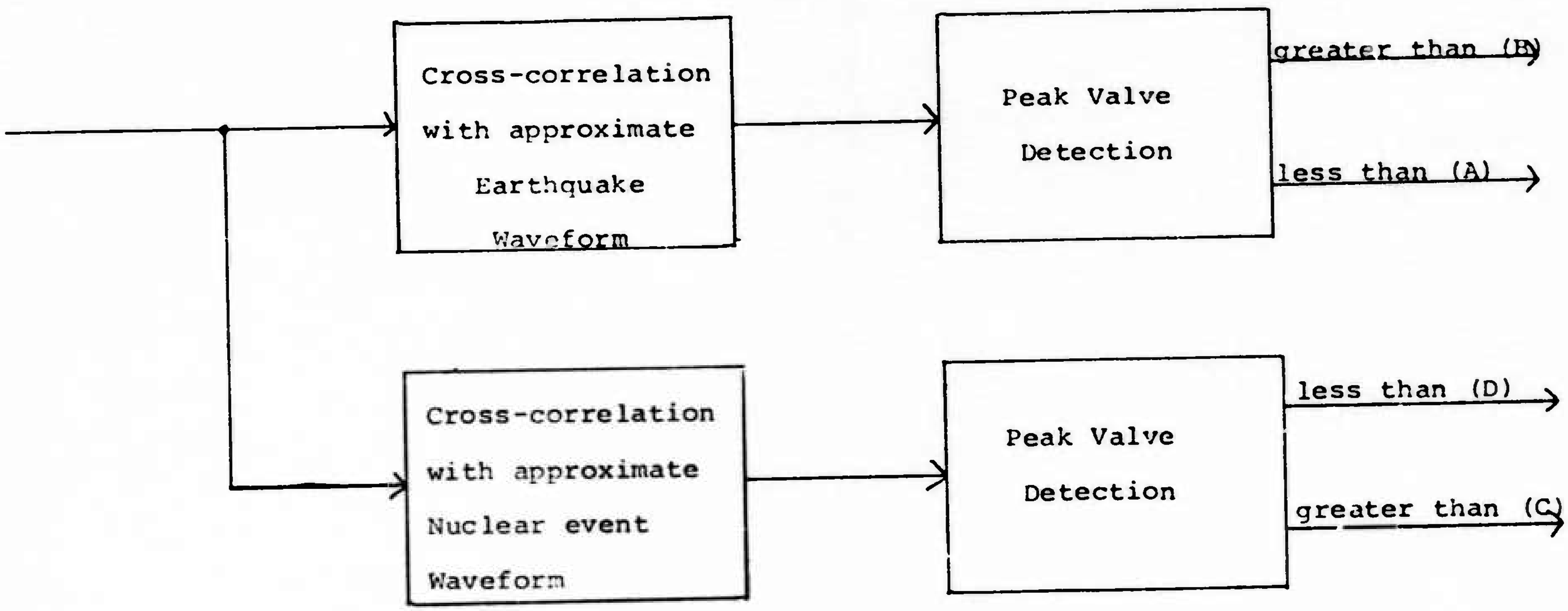


Figure 13

Cross-correlation of the P-wave arrivals for a nuclear shot and natural event.



If (A and C) Possible Shot

If (B and D) Possible Earthquake

If (B and C) or (A and D) Event Unknown

Figure 14

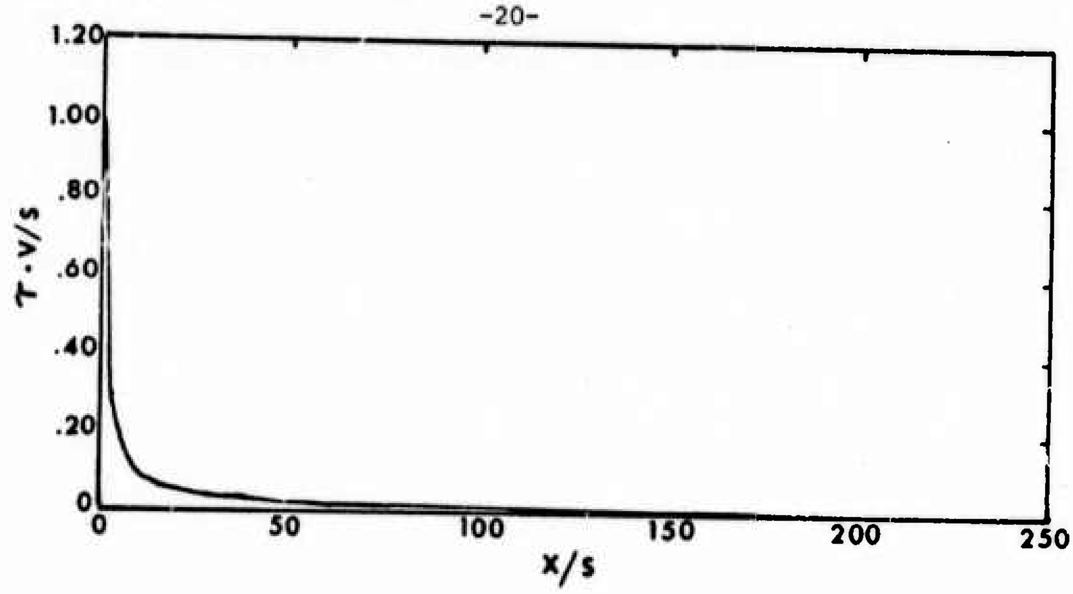
Identification logic, based on cross-correlation methods, for an unmanned observatory.

Cepstrum Analysis

Cepstrum analysis provides a means for the detection of secondary arrivals hidden within the first arrival. The utility of the method is dependent upon, among other things, the purity and uniqueness of the secondary arrival. Selected applications of the method have yielded promising results (Flinn et al., 1973; Cohen, 1970). These applications, however, are limited in number and may not represent typical results.

The use of measured delay in the secondary arrivals as a function of source distance and azimuth initially appears as a potential means for improving the reliability of any Cepstrum based detection method. The dependence of measured delay on source distance for vertically and horizontally separated sources is shown in Figures 15 and 16, respectively. The upper figure in each case is in dimensionless parameters while the lower figure indicates the actual values involved for a 1 km source separation. It is evident from these two figures that no source distance dependence exists at any range where an unmanned observatory could be established. (While Figures 15 and 16 apply to the P arrivals from two sources the slap-down signal from a single source would exhibit a constant delay at all ranges and would, thus, be similar to these figures.) The lack of any significant distance dependence provides a potential means for eliminating false identifications based on the detection of secondary arrivals within the initial wave-train of an earthquake.

The dependence of measured delay on azimuth is shown in Figure 17 for horizontally separated events. Vertically separated events would produce a constant delay at all azimuths. It is presently felt that the dependence of delay on azimuth probably lacks sufficient uniqueness to yield any significant measure.



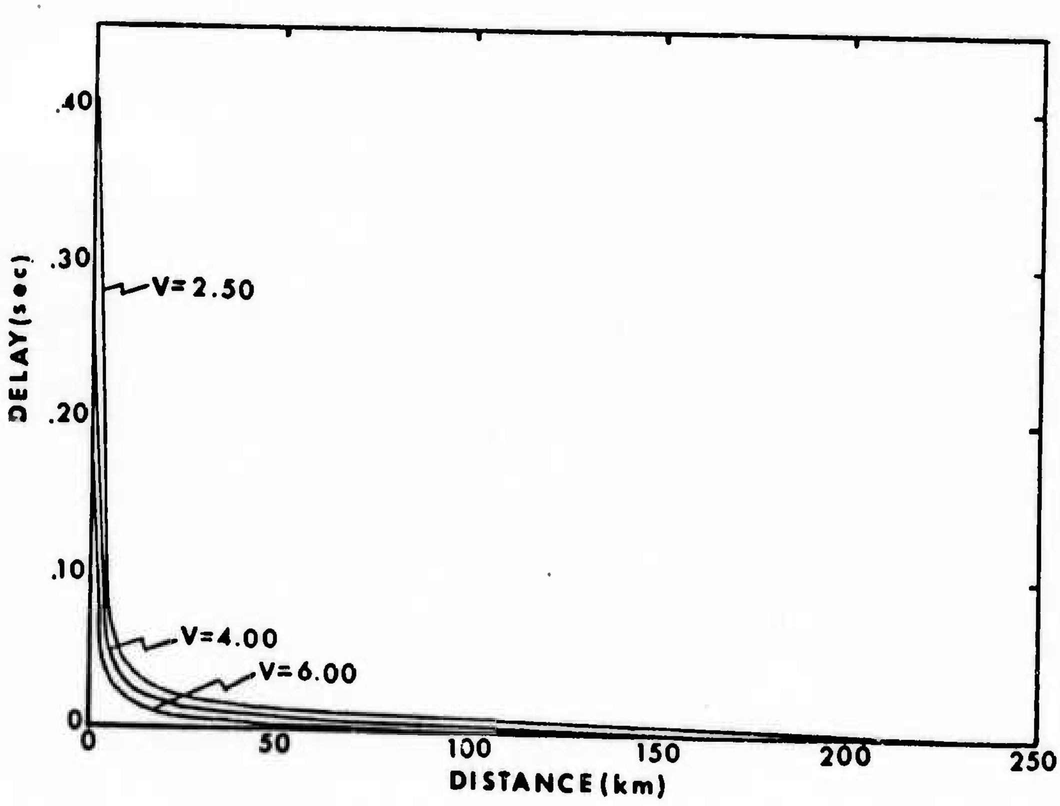


Figure 15

Theoretical delay in P-wave arrivals for vertically separated events. Lower figure is for an event separation of 1 km. Upper figure is dimensionless.

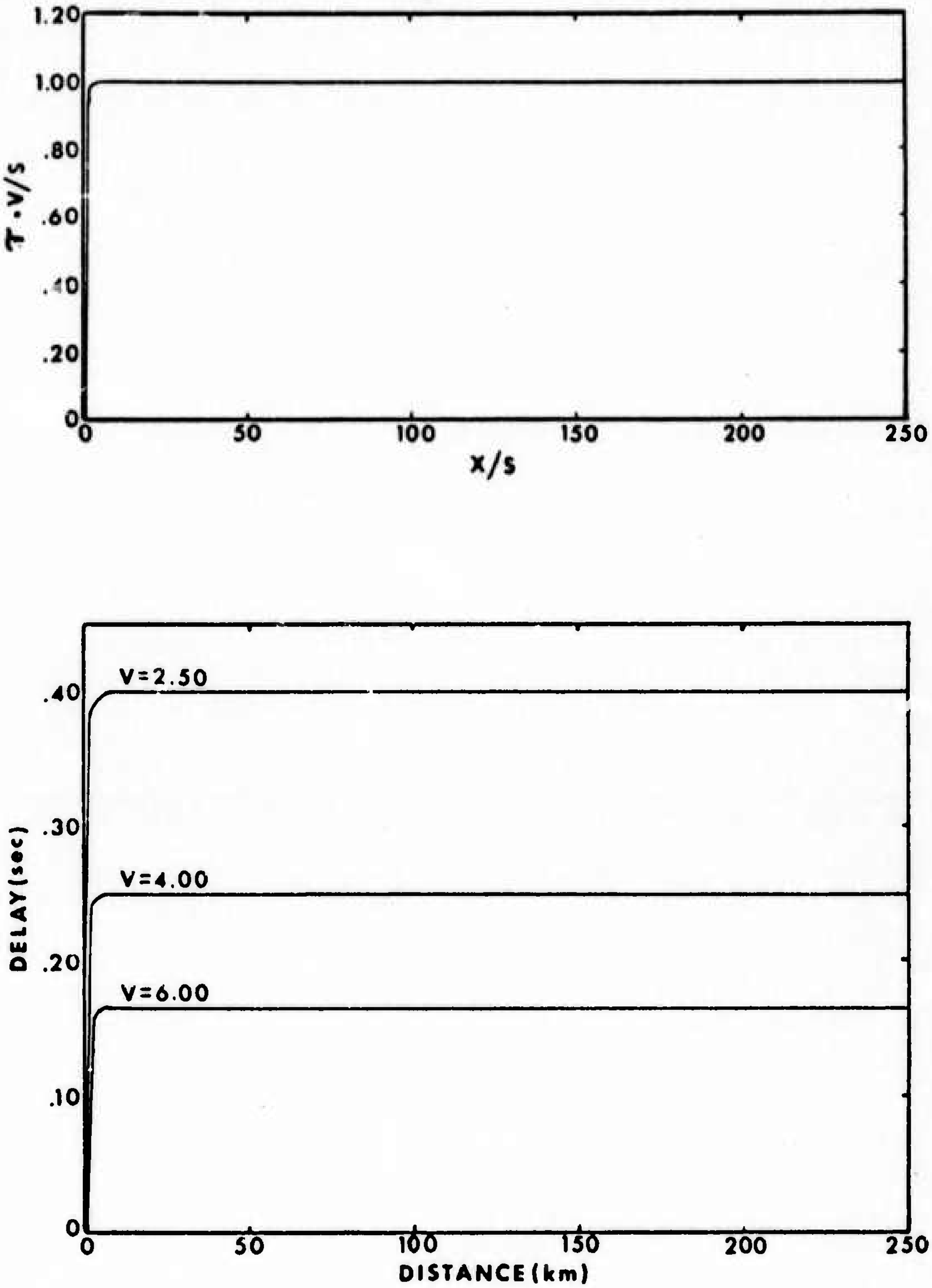


Figure 16

Theoretical delay for P-wave arrivals from horizontally separated sources. Lower figure for a source separation of 1 km. Upper figure is dimensionless.

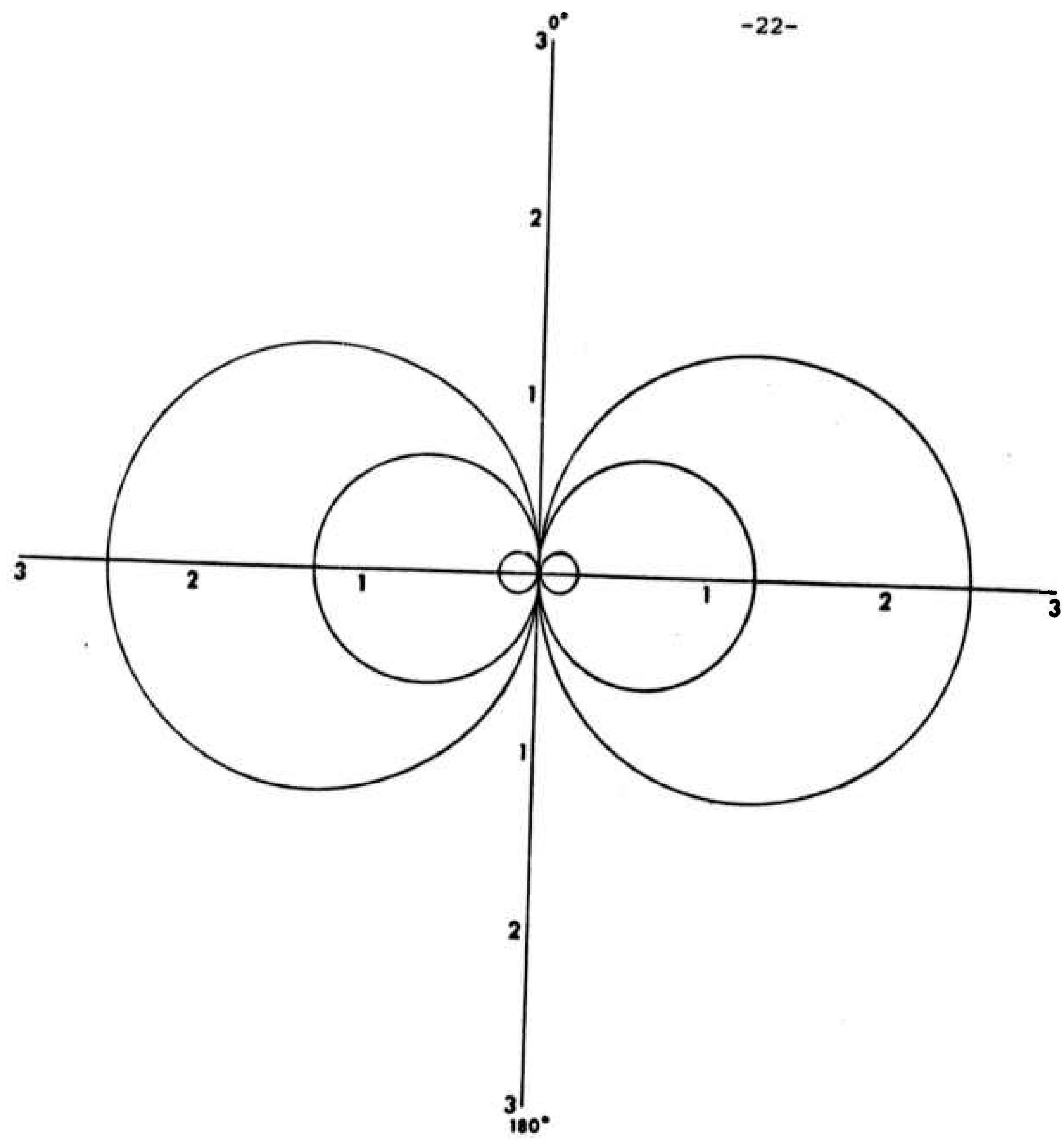


Figure 17

Theoretical delay in P-wave arrivals as a function of azimuth for horizontally separated events.

Typical Cepstrum values calculated for two window lengths are shown in Figures 18 and 19 for Event-B. The strong influence of window length on the resulting Cepstra is evident and tends to degrade the utility of Cepstrum analysis for use in connection with unmanned observatories. A typical Cepstrum for the Massachusetts Mountain earthquake is shown in Figure 20. The Cepstrum is more complex than that of Event-B and exhibits a far greater number of peaks. This reflects the increased complexity of secondary arrivals associated with this event. At present, however, the data base is not sufficiently extensive to yield firm generalizations.

The Cepstrum measured delay times as a function of distance are shown in Figure 21 for Event-B. It should be noted that the station azimuths in this figure are not constant. While some scatter exists in the data, there appears to exist a fairly consistent secondary arrival at 0.65 seconds. The measured delays as a function of distance for the Massachusetts Mountain earthquake are shown in Figure 22. (As with Event-B, the station azimuths are not constant.) The scatter in the data appears somewhat higher than that associated with Event-B. The figure does, however, suggest the existence of a secondary arrival at 0.65 seconds.

The delays in secondary arrivals as a function of azimuth for Event-B are shown in Figure 23 and appear to be independent of azimuth. The delays in secondary arrivals as a function of azimuth for a natural event are shown in Figure 24. Because of limited station coverage, the station distances in both these figures are not held constant.

At present, the data base associated with Cepstrum analysis is insufficient to yield firm conclusions. Application of the method to

CEPSTRUM-EVENT-B-MEDIUM GAIN-LAC
DATA WINDOW .00 to 22.40 SEC

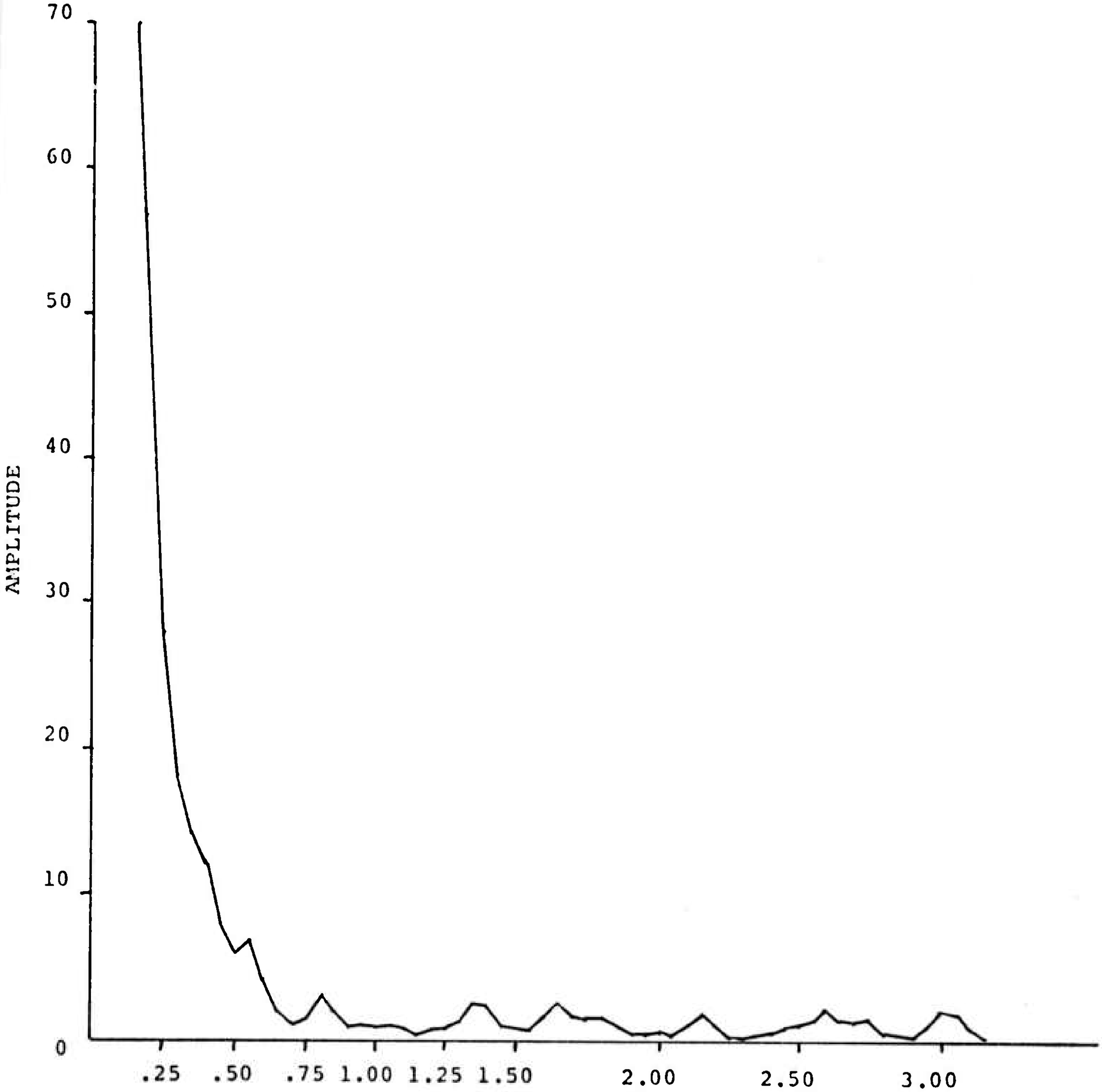


Figure 18

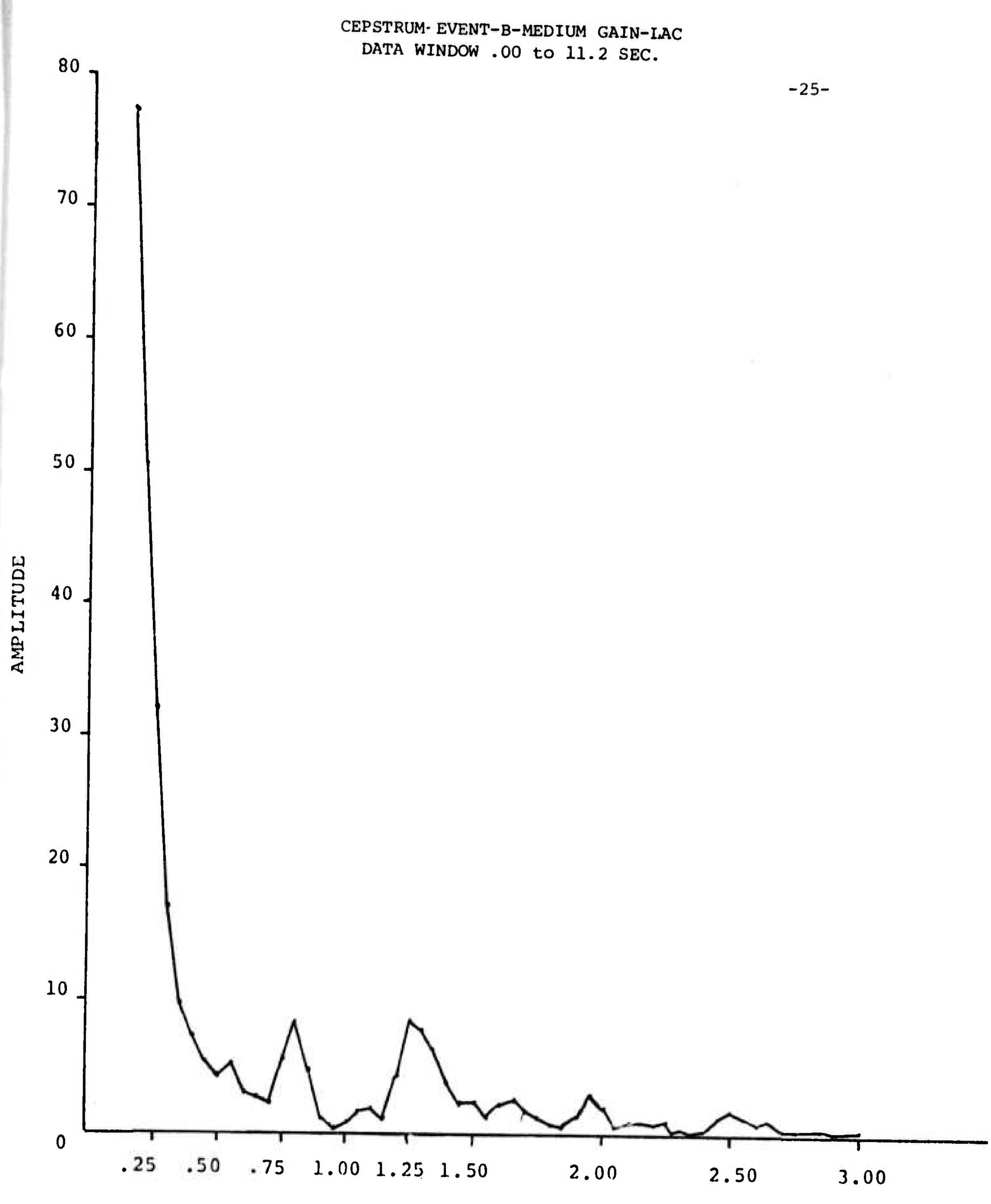

CEPSTRUM-EVENT-B-MEDIUM GAIN-LAC
DATA WINDOW .00 to 11.2 SEC.
AMPLITUDE
80
70
60
50
40
30
20
10
0
.25
.50
.75
1.00
1.25
1.50
2.00
2.50
3.00

Figure 19

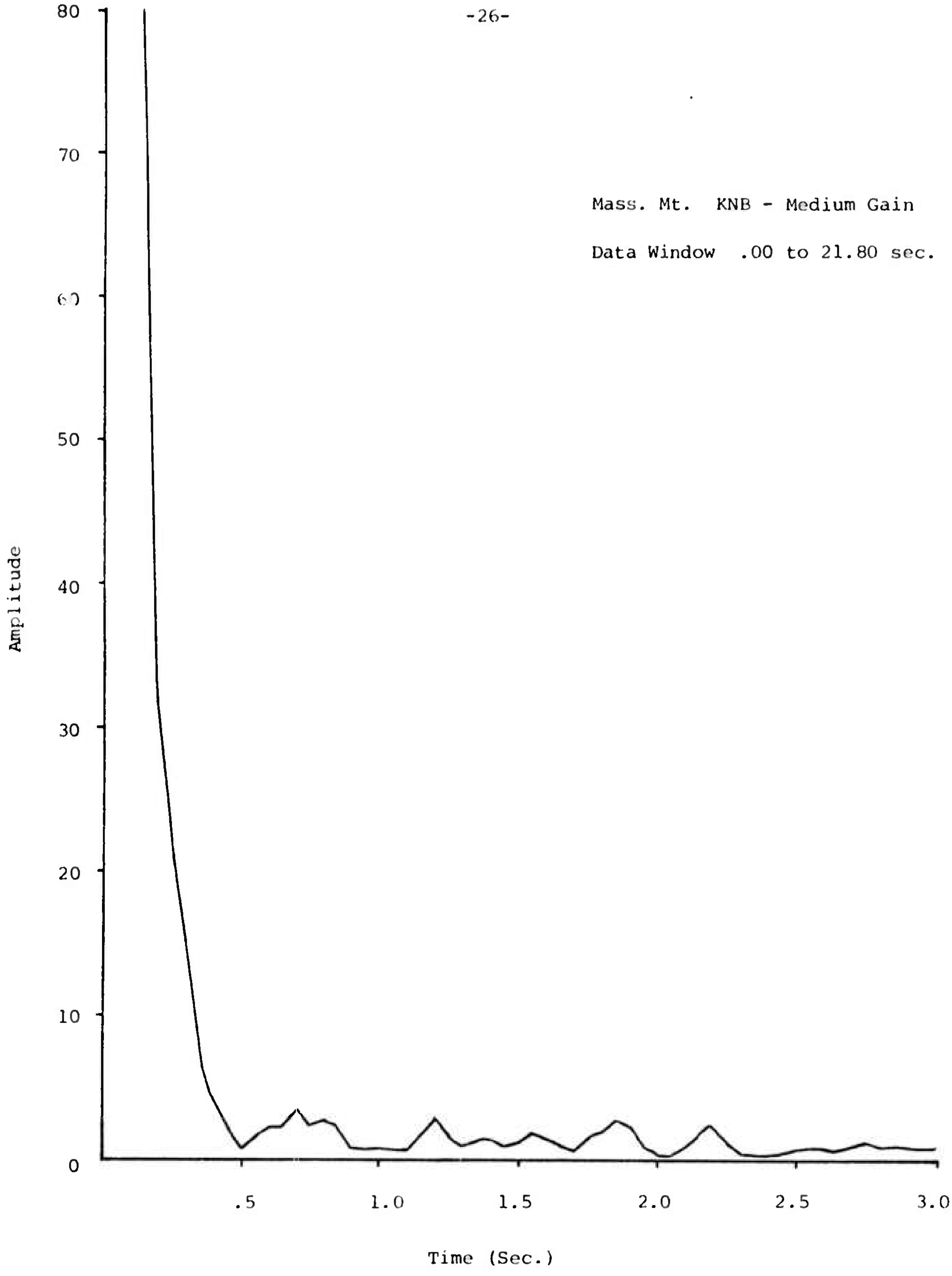


Figure 20

Cepstrum for P-wave arrivals of a natural event.

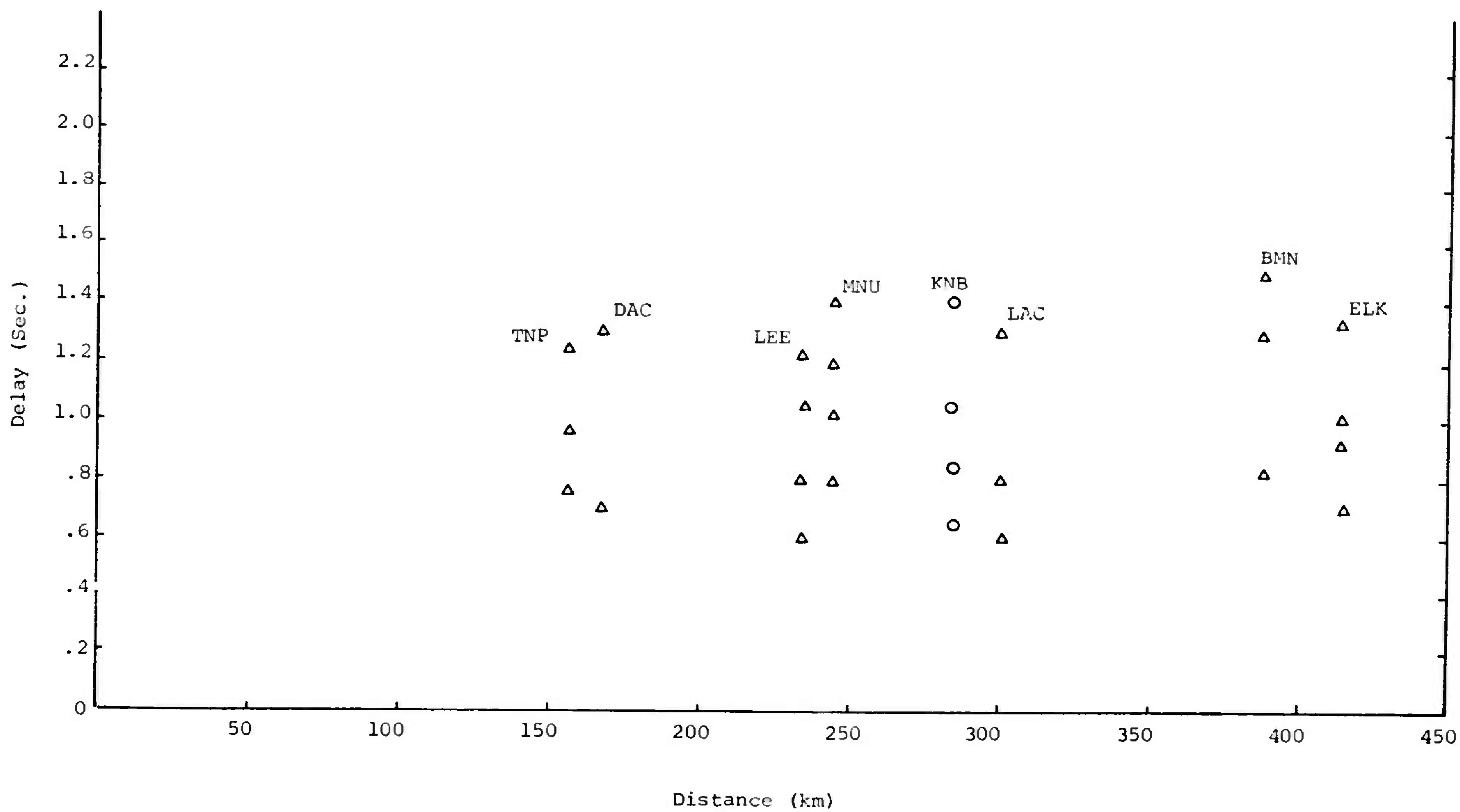


Figure 21

Cepstrum measured delays for P-arrivals from nuclear shot Event-B. The open triangles indicate consistent results on vertical and radial components, open circles indicate results from vertical component only.

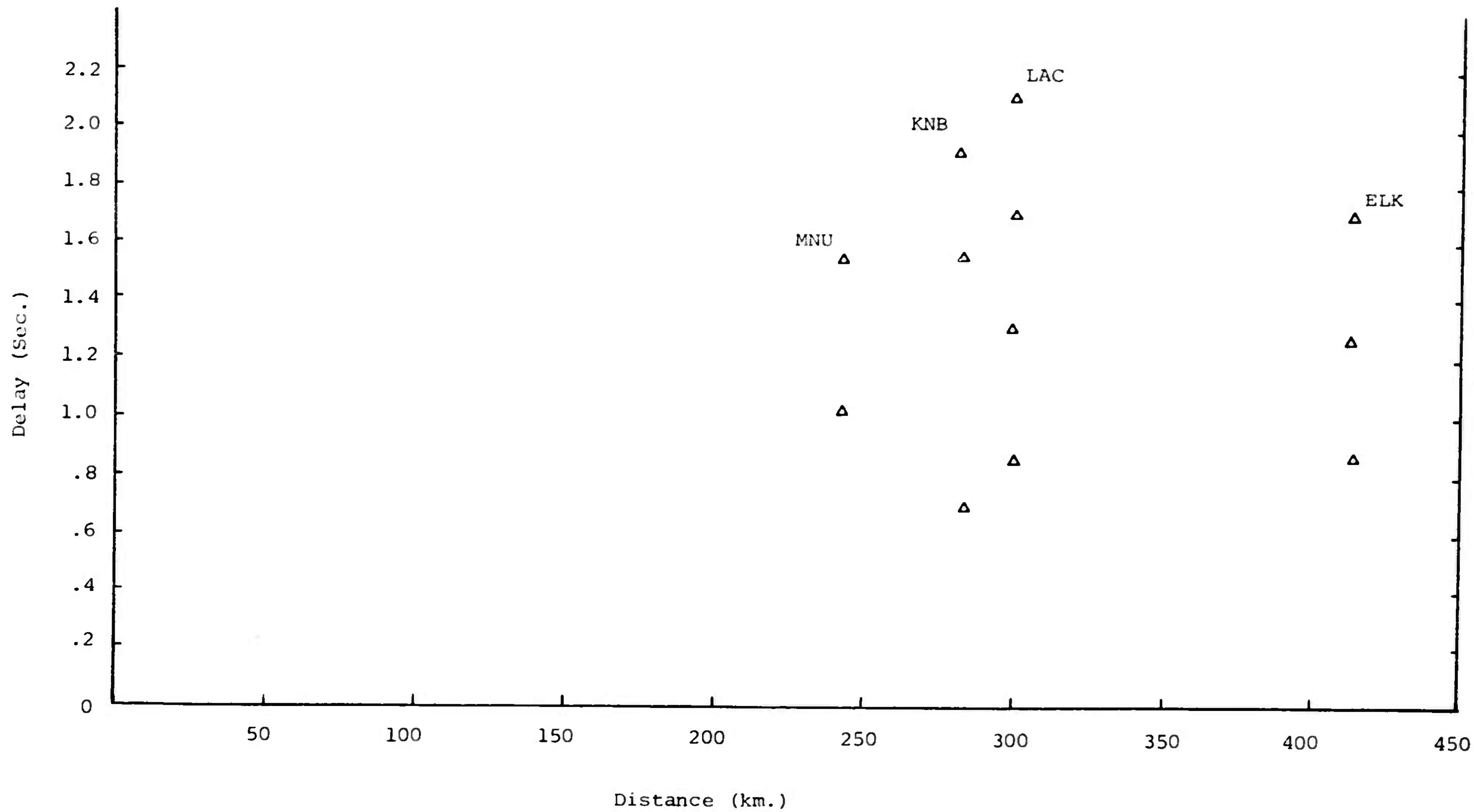


Figure 22

Cepstrum measured delays within P-wave arrivals of Massachusetts Mountain earthquake.

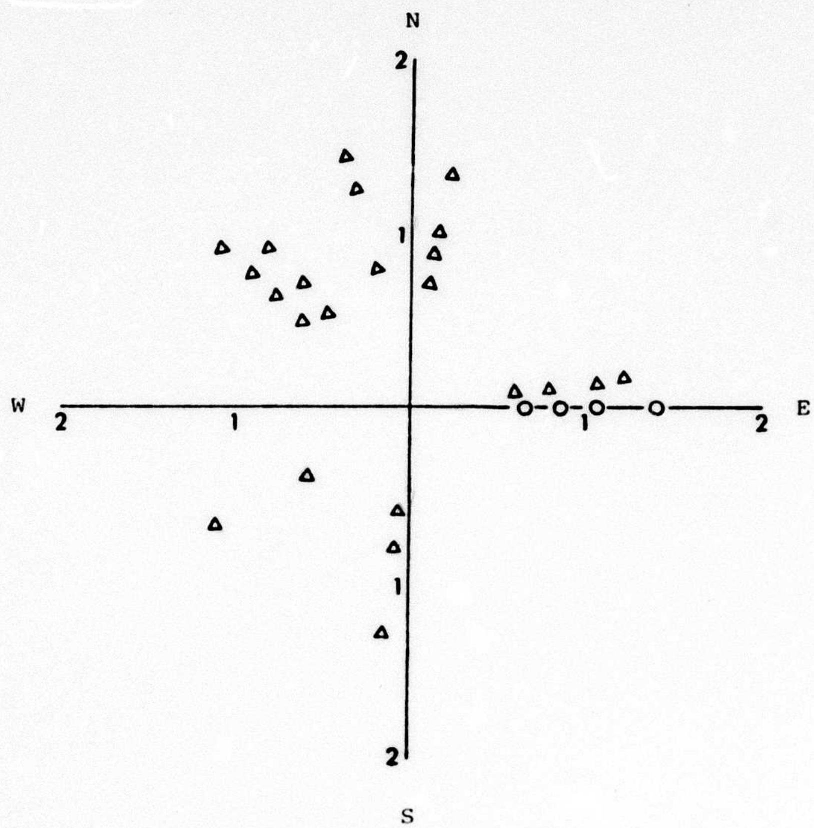


Figure 23

Cepstrum measured delays in secondary arrivals as a function of azimuth for nuclear shot Event-B. The open triangles indicate consistent results on vertical and radial components, open circles indicate results from vertical compenent only.

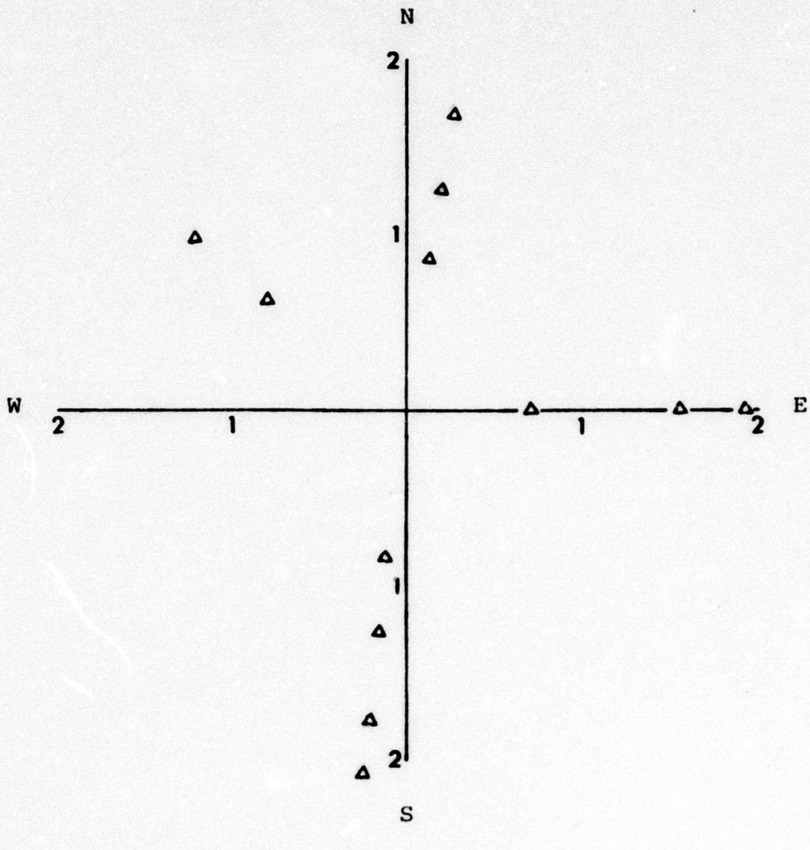


Figure 24

Cepstrum measured delays in secondary arrivals as a function of azimuth for Massachusetts Mountain earthquake.

other nuclear events is presently underway. On a preliminary basis, however, it appears that Cepstrum analysis does not provide sufficient uniqueness to yield positive identification from any reasonable station coverage.

Requirements of Station Coverage

A copy of the FORTRAN program NETWORK, initially developed by NOAA for the Atomic Energy Commission, was obtained from Tarr (1974). The program is presently being modified for operation with the UNIVAC 1110 of the University of Wisconsin-Milwaukee.

Following successful modification of the program, the effects of station coverage on detection potential will be investigated. While the requirements for identification will certainly exceed those for detection, the requirements for detection do place a lower bound on the necessary station coverage. It is anticipated that by combining detection requirements with potential methods for identification, it will be possible to obtain reasonable estimates of the effect of coverage on identification.

NTS Seismicity[-1]

Of interest to the general problem of the detection and identification of underground nuclear shots is the natural pattern of earthquake activity in a test site area and in changes of that activity due to the testing program. A detailed study was made of the Nevada Test Site seismicity for the time period 1 June 1969 through 1 March 1973. The earthquake data were obtained from the seismograph networks operated primarily by the U.S. Geological Survey - Menlo Park and the U.S. Geological Survey, Special Projects Group at Las Vegas (formerly the NOAA Special Projects Group). Some additional data were obtained from the University of California, Lawrence Livermore Laboratory network and the Sandia network.

The area included in this study is primarily the area covered by the Pahute Mesa and Yucca Flats nets. The area extends from 36° to 37.5° North and 115.5° to 117° West. The seismicity is displayed in Figures 25 through 30 as either the total number of earthquakes per week, the total accumulative strain release per week, or as accumulative weekly percentages of each over different time periods.

The two largest peaks shown in Figure 25 reflect the aftershock activity following JORUM (16th week, $m_b = 6.2$) and HANDLEY (43rd week, $m_b = 6.5$). Figure 31 contains the magnitudes of all of the significant shots fired during this 200-week period. There were 60 shots during this time period that had body wave magnitudes that ranged from 3.5 to 6.5. There were five additional shots that were too small for magnitudes to be determined. The shots below 6.0 did not appear to influence significantly

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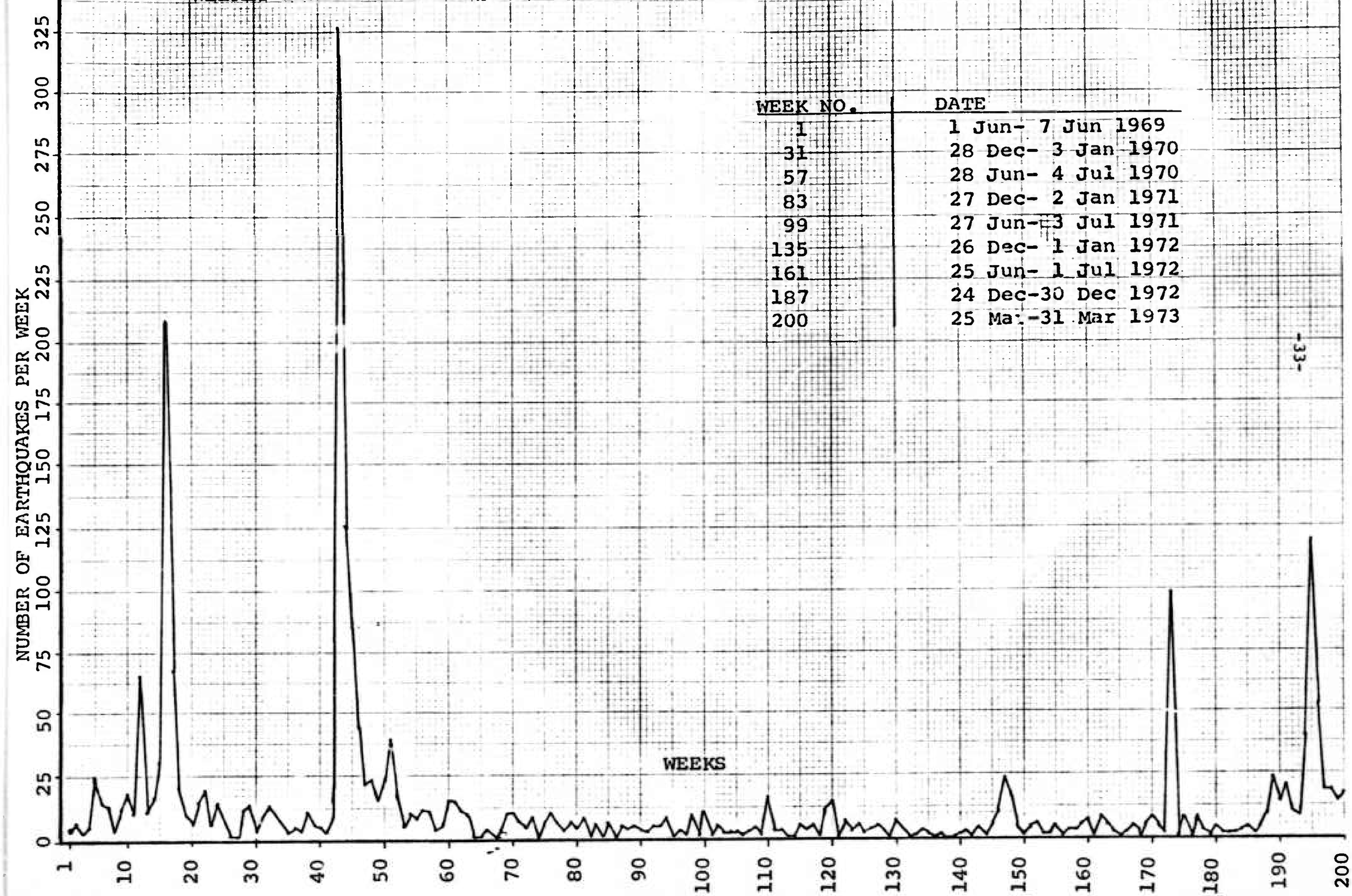
[-1] The work discussed in this section was co-sponsored by the Atomic Energy Commission Contract No. AT(11-1)-2138.

Figure 25

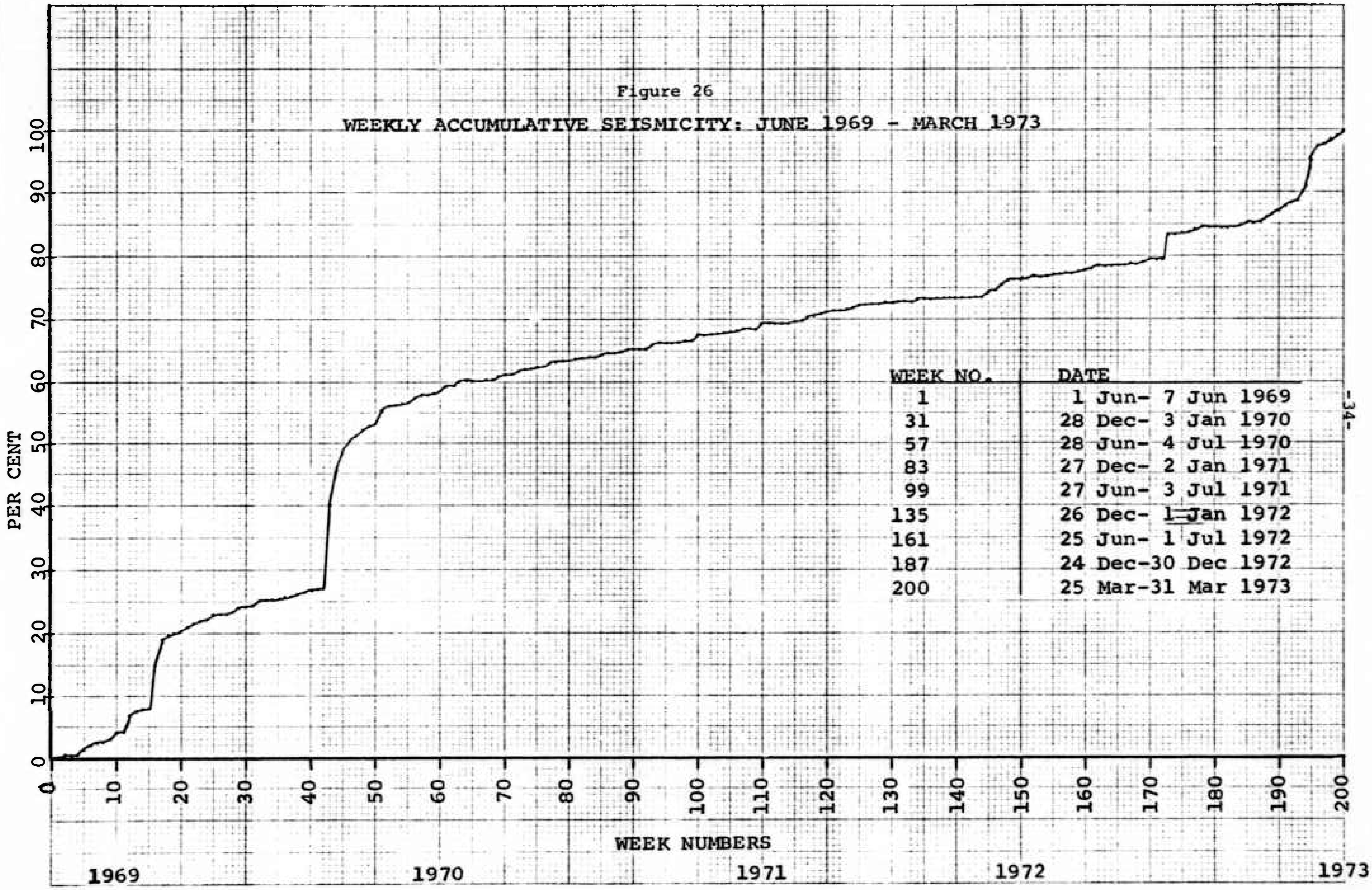
WEEKLY NUMBER OF EARTHQUAKES: JUNE 1969 THROUGH MARCH 1973



WEEK NO.	DATE
1	1 Jun- 7 Jun 1969
31	28 Dec- 3 Jan 1970
57	28 Jun- 4 Jul 1970
83	27 Dec- 2 Jan 1971
99	27 Jun- 3 Jul 1971
135	26 Dec- 1 Jan 1972
161	25 Jun- 1 Jul 1972
187	24 Dec-30 Dec 1972
200	25 Ma:-31 Mar 1973

Figure 26

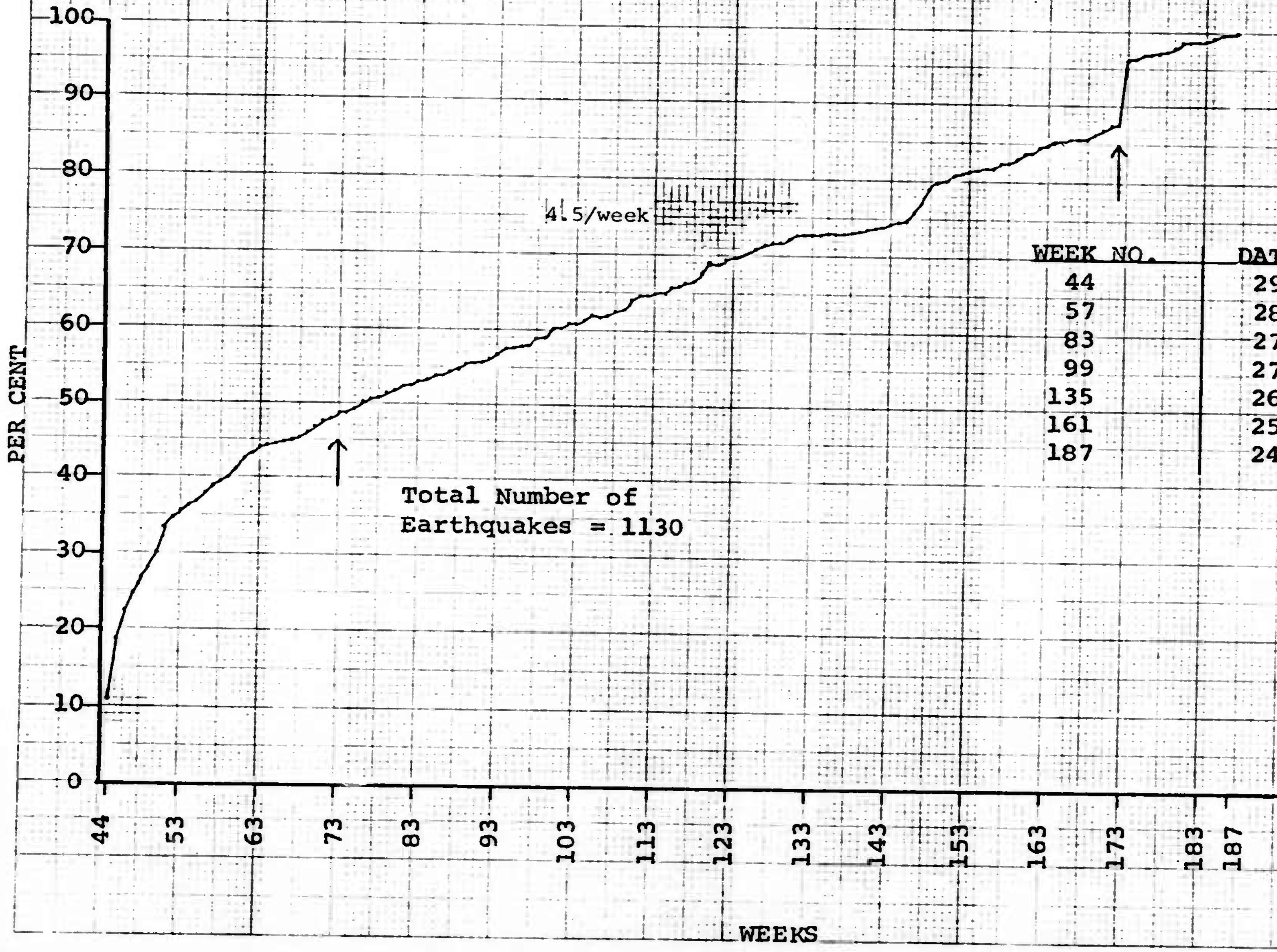
WEEKLY ACCUMULATIVE SEISMICITY: JUNE 1969 - MARCH 1973



WEEK NO.	DATE
1	1 Jun- 7 Jun 1969
31	28 Dec- 3 Jan 1970
57	28 Jun- 4 Jul 1970
83	27 Dec- 2 Jan 1971
99	27 Jun- 3 Jul 1971
135	26 Dec- 1 Jan 1972
161	25 Jun- 1 Jul 1972
187	24 Dec-30 Dec 1972
200	25 Mar-31 Mar 1973

Figure 27

WEEKLY ACCUMULATIVE SEISMICITY AFTER HANDLEY



WEEK NO.	DATE
44	29 Mar- 4 Apr 1970
57	28 Jun- 4 Jul 1970
83	27 Dec- 2 Jan 1971
99	27 Jun- 3 Jul 1971
135	26 Dec- 1 Jan 1972
161	25 Jun- 1Jul 1972
187	24 Dec-30 Dec 1972

Figure 28

WEEKLY STRAIN RELEASE AFTER HANDLEY

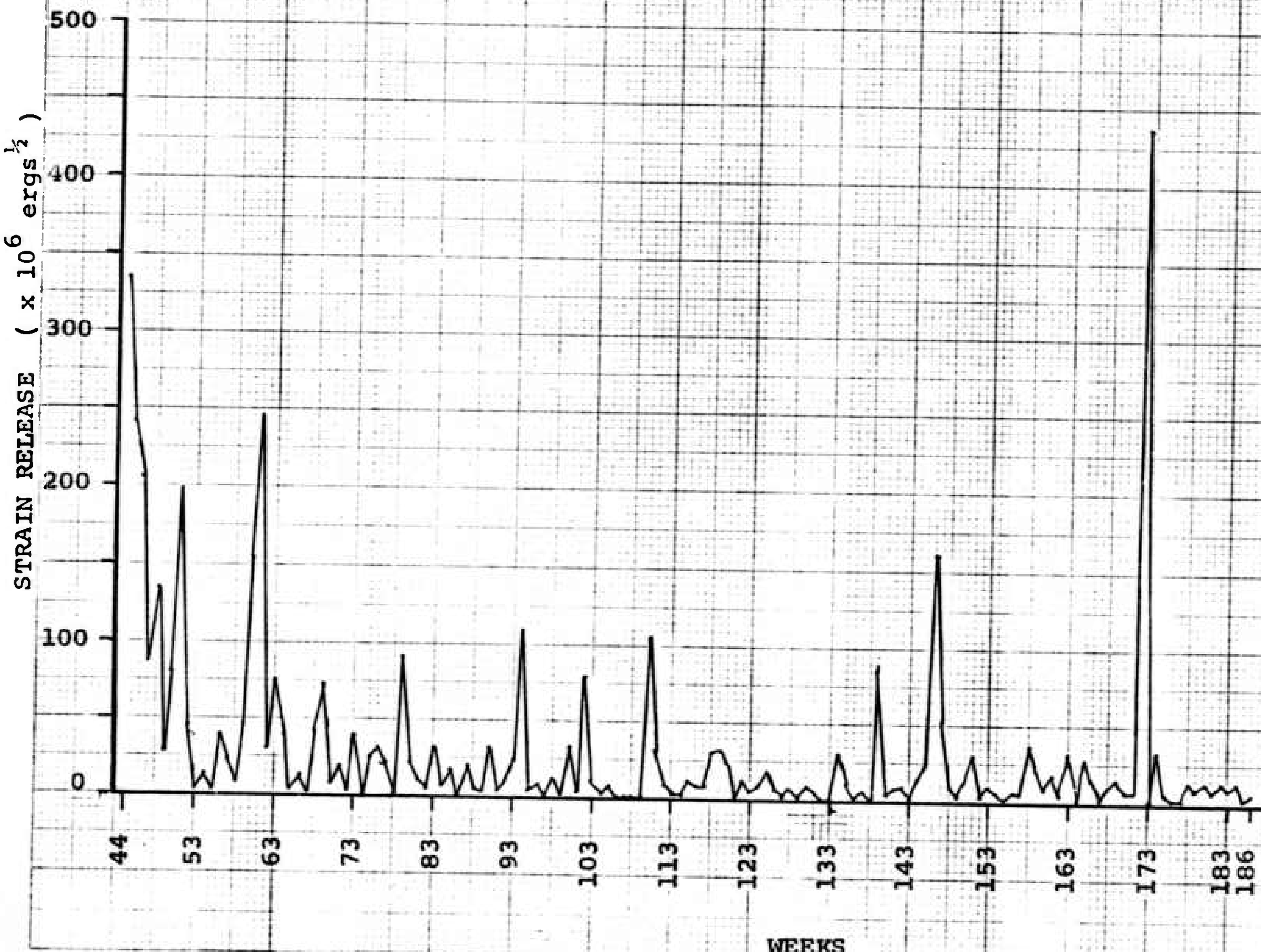
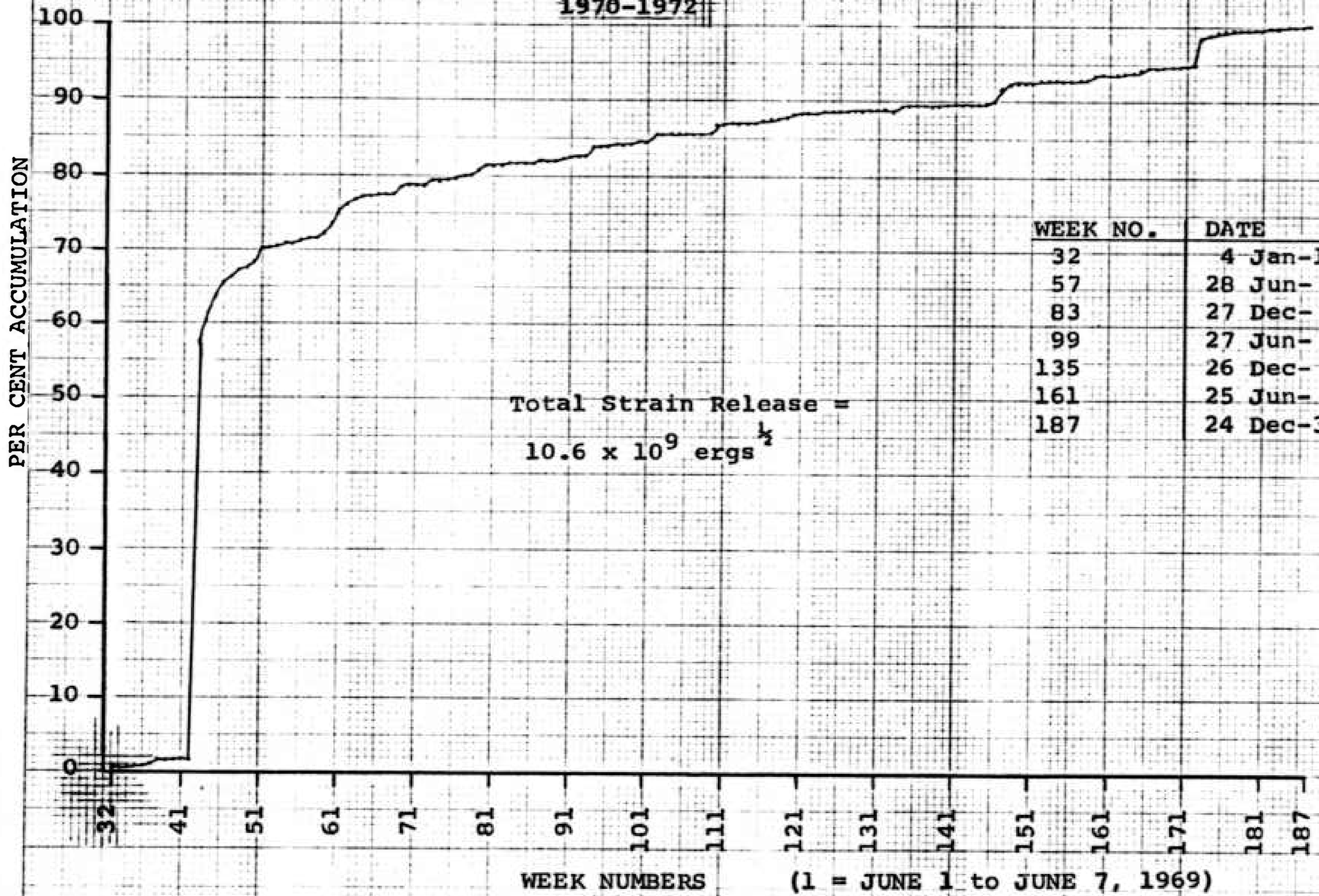


Figure 29

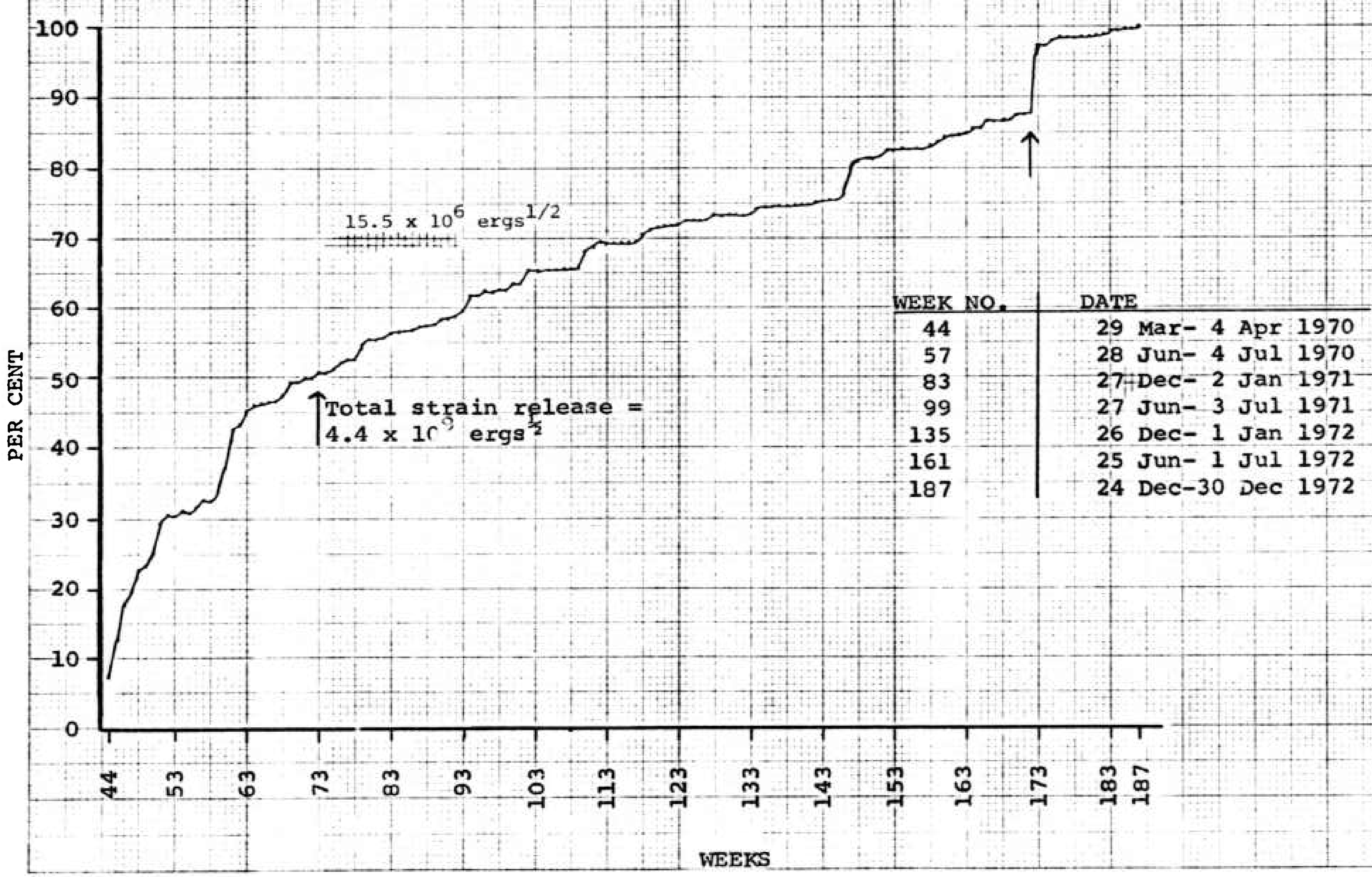
WEEKLY PER CENT STRAIN RELEASE ACCUMULATION
1970-1972



WEEK NO.	DATE
32	4 Jan-10 Jan 1970
57	28 Jun- 4 Jul 1970
83	27 Dec- 2 Jan 1971
99	27 Jun- 3 Jul 1971
135	26 Dec- 1 Jan 1972
161	25 Jun- 1 Jul 1972
187	24 Dec-30 Dec 1972

Figure 30

WEEKLY PER CENT ACCUMULATIVE STRAIN RELEASE AFTER HANDLEY



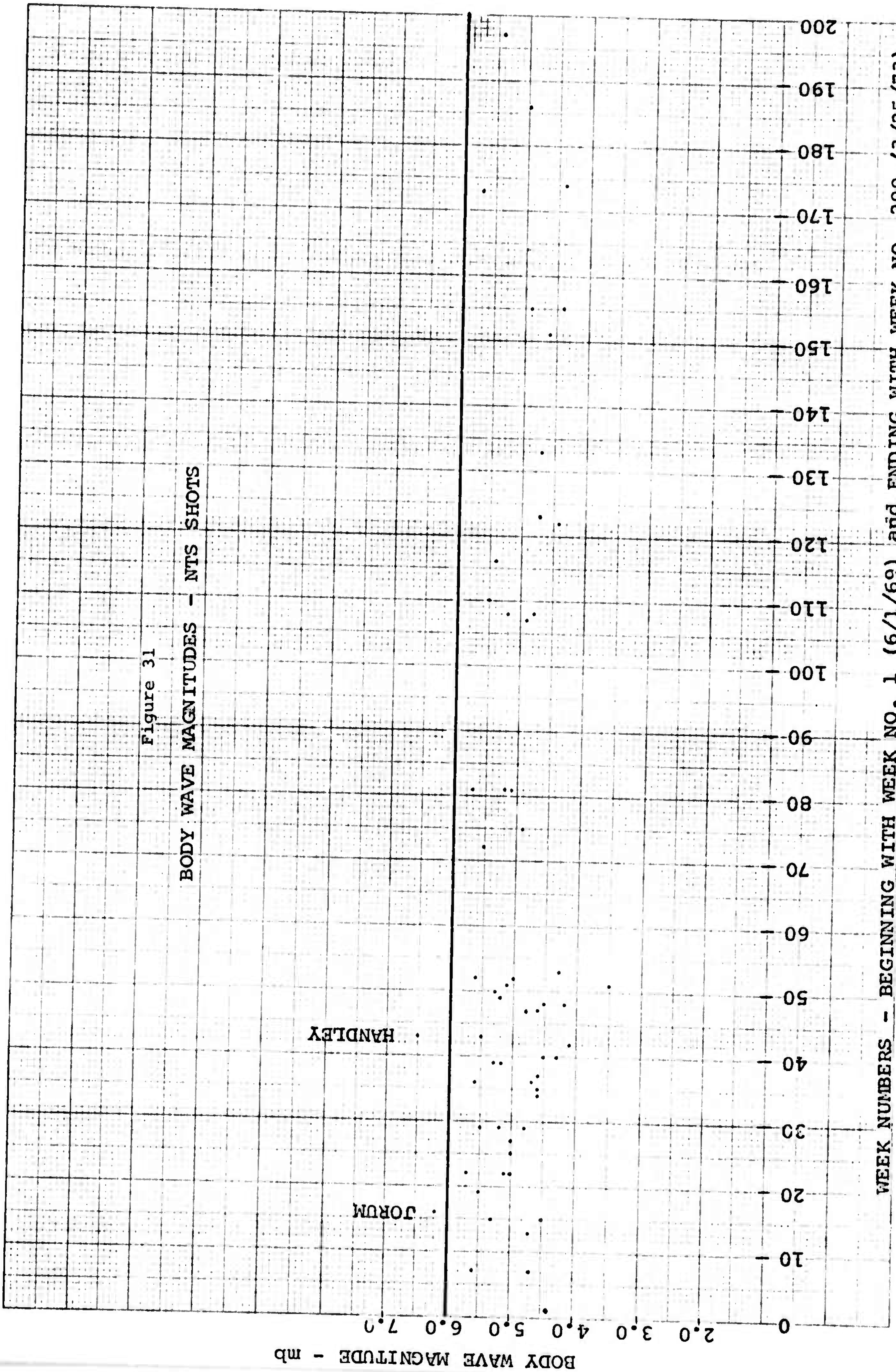


Figure 31

BODY WAVE MAGNITUDES - NTS SHOTS

the normal seismicity for this area with the exception of the shot fired during the 173rd week and possibly the 110th week. The intense shot activity during the 47th through 53rd weeks may also have perturbed the natural seismic pattern. However, the perturbation may be part of the aftershock activity caused by HANDLEY. The three large shots fired during the 81st week (the largest of which was 5.7) did not affect the seismic pattern as seen in both the strain release and weekly number of earthquakes.

The data base is not consistent throughout this 200-week period. Beginning at approximately the 188th week (Dec. 31, 1972) the number of seismograph stations in operation was reduced considerably by the closing of the U.S.G.S.-Menlo Park network. Hence, the weekly number of earthquakes shown for 1973 is a conservative number because of the smaller station control. It is interesting to note, however, that during this time period the number of earthquakes reported was higher than the average for the preceding 130 weeks indicating that there was a true increase in seismicity during the first 3 months of 1973. Strain release was not computed for this time period because most of the earthquakes reported did not have computed magnitudes. Those earthquakes that did have computed magnitudes ranged in value from 2.9 to 4.2. The number of earthquakes with magnitudes above 3.9 shows that the strain release for this period is also higher than average.

A Spearman's rank analysis for these data is shown below:

Time Period	Number of Earthquakes/Week Rho	Strain Release/Week Rho
1. 1 June 1969-25 March 1973 (Week No. 1 thru 200)	-.2327	
2. 4 Jan. 1970-thru 1972 (Week No. 32 thru 187)	-.3572	-.3320
3. After HANDLEY-thru 1972 (Week No. 44 thru 187)	-.0880	-.1464
4. After HANDLEY-thru 25 March 1973 (Week No. 44 thru 200)	+.17752	

Rho, the Spearman's rank correlation coefficient, can vary between +1 and -1. Rho near -1 is strong evidence of a decreasing trend, near +1 indicates strong evidence of an increasing trend. Overall the seismicity appears to be decreasing. Eliminating the period of time prior to two weeks following HANDLEY (see line 3 above) it can be seen that there is a small decrease in seismic activity over a time period of 143 weeks. This is interpreted to represent more or less the natural seismicity for the area. Referring to Figures 27 and 30 for the time periods shown, the number of earthquakes per week and the strain release per week is approximately 4.5 and 15.5 x 10^6 $ergs^{1/2}$, respectively. The positive value of Rho is caused by the increased natural activity in early 1973.

These data will be studied further in relationship to the tectonics of the area.

Regional Magnitude Variations[-1]

Magnitude estimates from underground nuclear explosions have been found to exhibit regional patterns of highs and lows across the United States (Mickey, 1963; Guyton, 1964; Willis and others, 1973). Asymmetry in radiation patterns from a radially symmetric source could result from the relaxation of prestress in the source region, changing geologic conditions along the transmission path, or differences in local geology at the seismograph stations.

In an analysis of body and surface wave radiation patterns for six NTS shots (HANDLEY, JORUM, GREELEY, PILE DRIVER, BOXCAR, and BENHAM) and three shots on Amchitka Island (LONGSHOT, MILROW, and CANNIKIN), consistent regional anomalies could be discerned. Iso-magnitude plots for HANDLEY, JORUM, and CANNIKIN are given in Figures 32, 33, and 34, respectively. In order to reduce instrumental variation, all stations used were either from the World Wide Standard Seismic Network (WWSSN) or the Canadian Seismic Network (CSN). As a point of reference, m_b magnitudes (using Richter's body wave magnitude equation without applying station corrections) were determined as follows: HANDLEY - 6.61, JORUM - 6.48, CANNIKIN - 7.07.

Figure 32 shows a zone of low magnitudes determined for HANDLEY extending across most of Canada, a relatively high zone along the east coast coinciding with the Appalachians, and a predominant positive anomaly in the northwestern portion of the United States.

The pattern for JORUM in Figure 33 is similar, except for the prevailing low magnitudes in British Columbia and Vancouver Island (stations PHC, VIC, and PNT).

-1 The work discussed in this section was co-sponsored by the Atomic Energy Commission Contract No. AT(11-1)-2138.

Figure 32

Iso-magnitude contour map of body wave magnitudes for the HANDLEY underground nuclear explosion. Contour interval is .4 m_b. The star indicates the shot location, and the dots show the distribution of seismograph stations used in magnitude calculations.

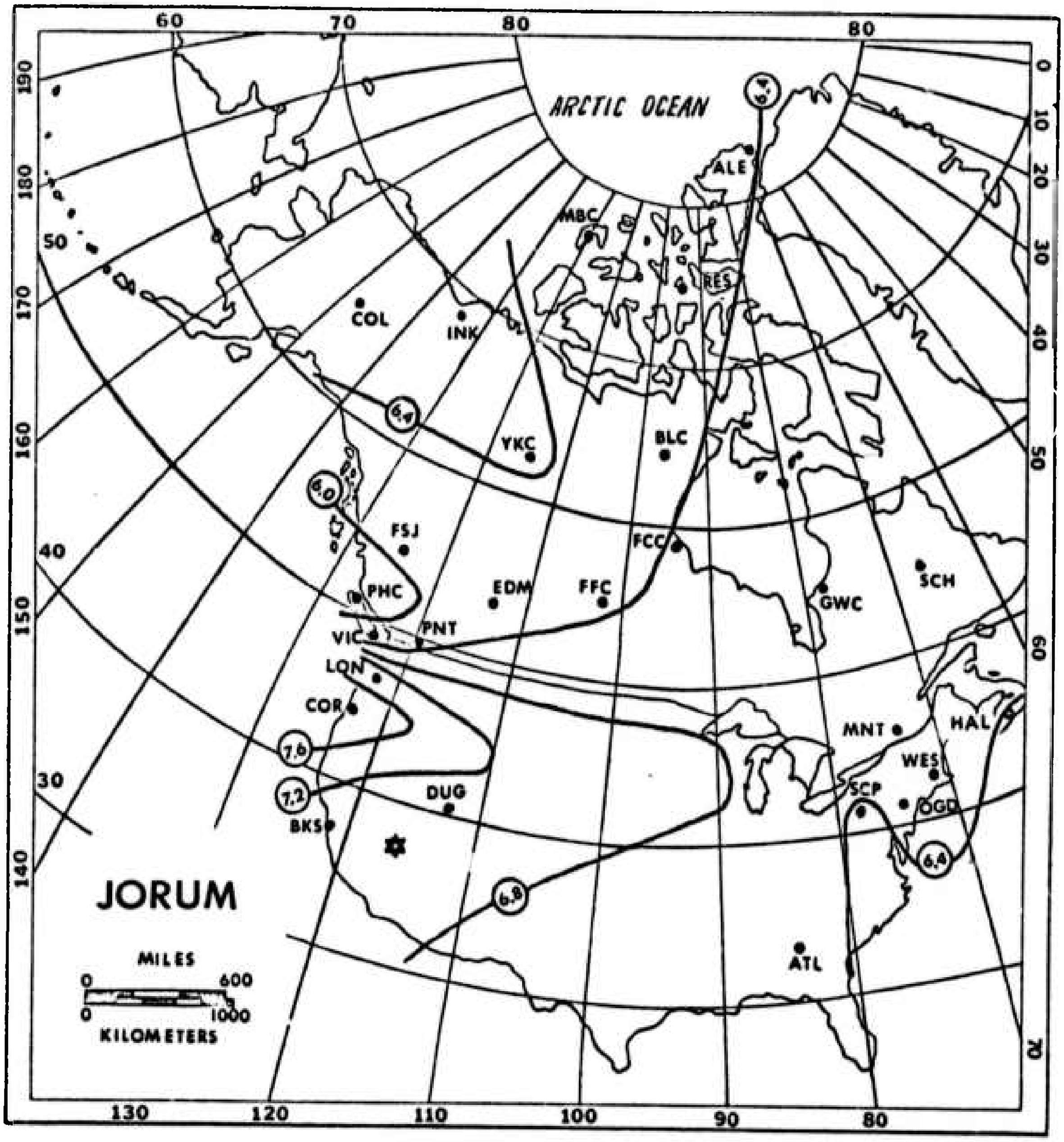


Figure 33

Iso-magnitude contour map of body wave magnitudes for the JORUM underground nuclear explosion. Contour interval is .4 m_b. The star indicates the shot location, and the dots show the distribution of seismograph stations used in magnitude calculations.

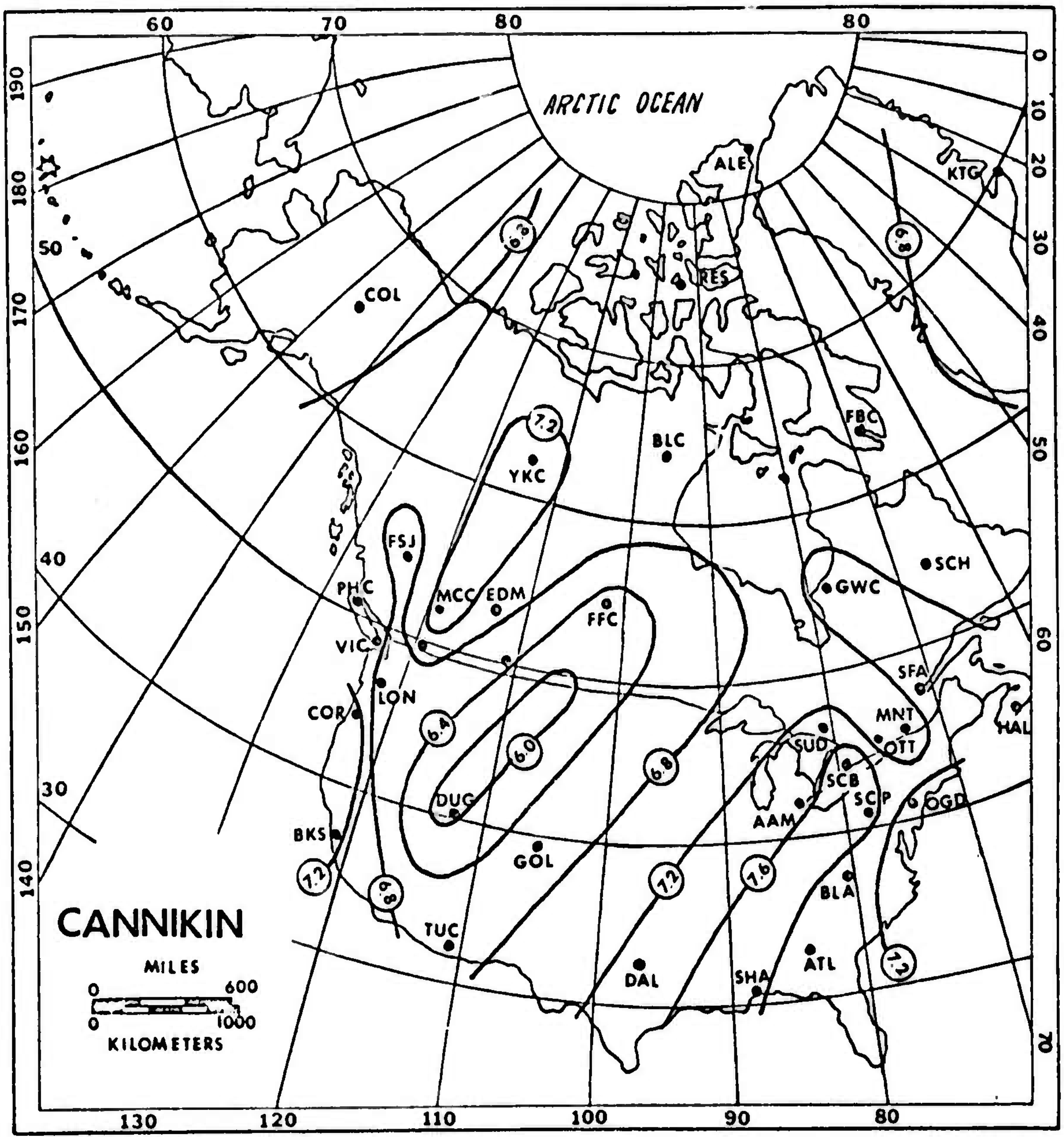


Figure 34

Iso-magnitude contour maps of body wave magnitudes for the CANNIKIN underground nuclear explosion. Contour interval is .4 m_b. The star indicates the shot location, and the dots show the distribution of seismograph stations used in magnitude calculations.

CANNIKIN, being from an entirely different source region, has quite different propagation paths. However, similarities in magnitude anomalies exist. A belt of high magnitudes occurs along the Appalachians, covering the eastern third of the United States. Distinct lows are evident in the western United States, especially across the Rocky Mountains, the Colorado Plateau, and the Basin and Range Province.

The m_b and M_s magnitude deviations for the nine nuclear shots previously mentioned in this section are presented in Figures 35 and 36, respectively. For each shot an average magnitude was determined, and from that, an average deviation for each station was calculated. A prominent peak of m_b values centers over Corvallis, Oregon, once again spreading across the northwest corner of the United States. Negative body-wave deviations are observed across most of Canada. A smaller positive anomaly can be seen in the Gulf Coastal Plain.

Magnitude variations are more regionally consistent and geologically correlated using deviations from average M_s estimates. Figure 36 reveals dominant highs stretching over the eastern third of the United States, the highest values falling along the northern reaches of the Appalachians. The high positive magnitude belt across most of eastern Canada correlates with the Canadian Shield. Most striking is the region of negative deviations in the western third of the United States, which extends northward into the two western provinces of Canada. This region of negative deviations appears bounded on the east by the Rocky Mountains. The largest negative anomaly occurs in the southwest from the Pacific Border Province through most of the Basin and Range Province.

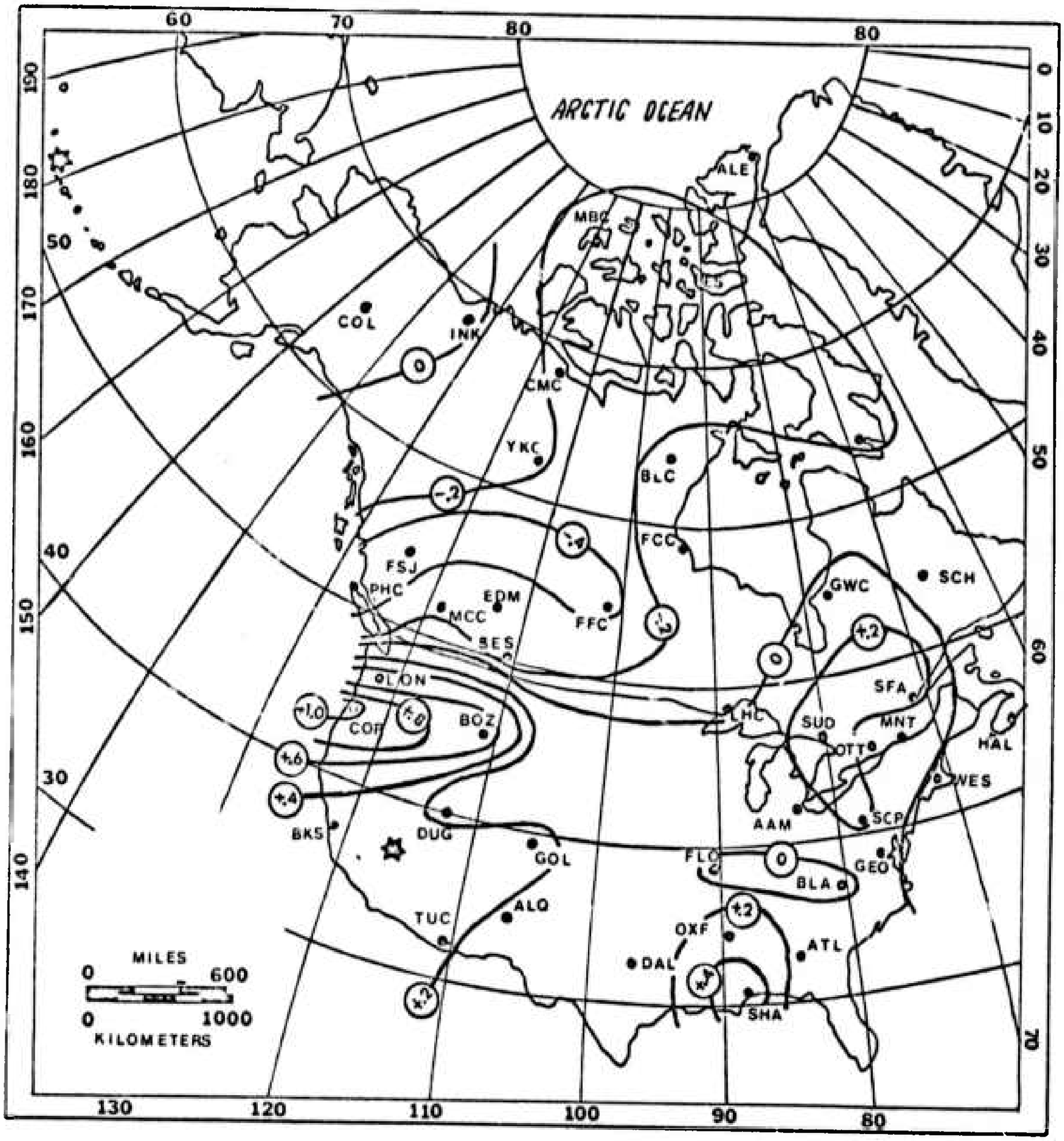


Figure 35

Contour map of average deviations for the m_b magnitudes of six NTS explosions (PILE DRIVER, GREELEY, BOXCAR, BENHAM, JORUM, HANDLEY) and the CANNIKIN explosion on Amchitka Island. The stars indicate the shot locations and the dots show the distribution of seismograph stations used in magnitude calculations.

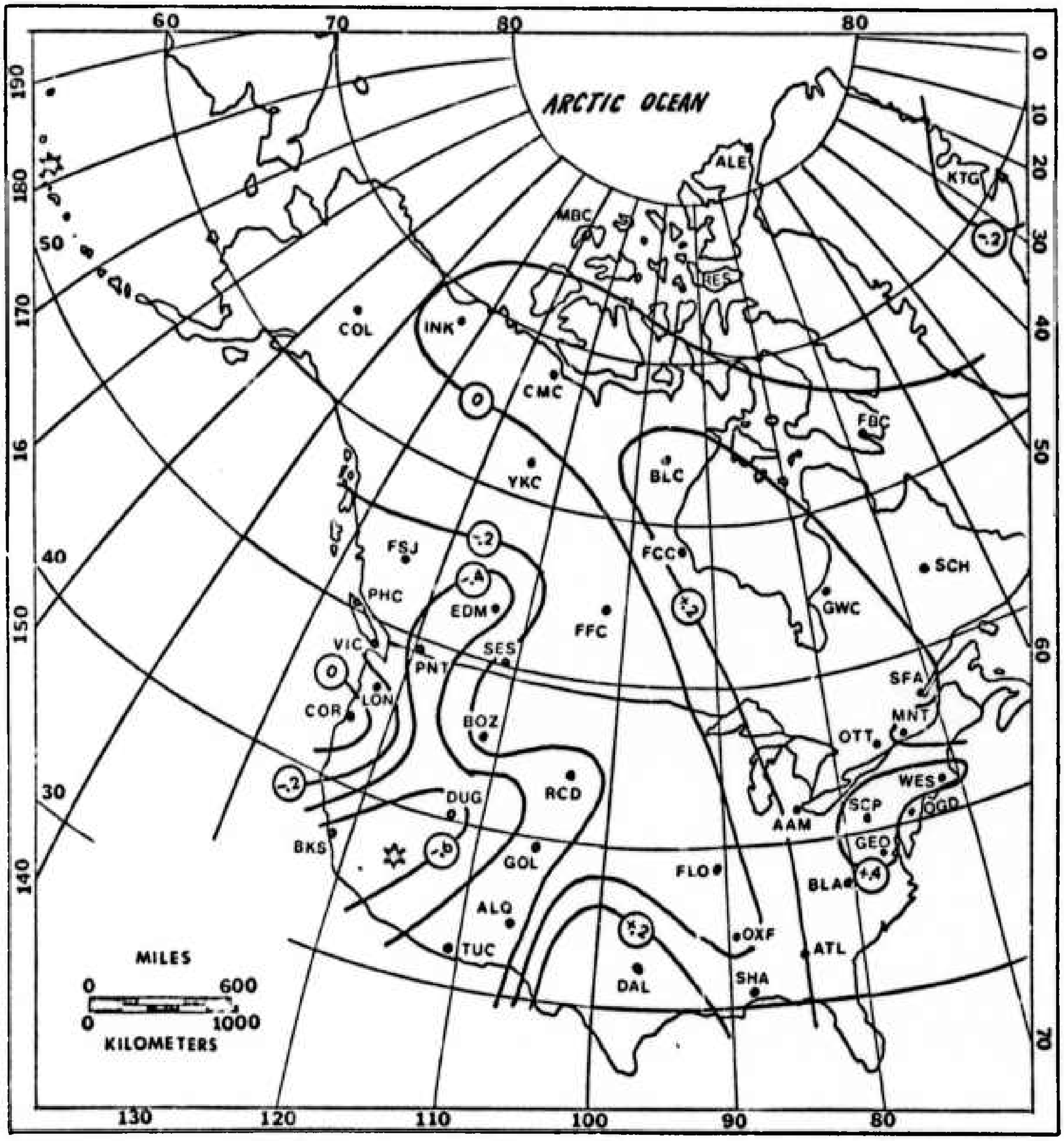


Figure 36

Contour map of average deviations for the M_S magnitudes of six NTS explosions (PILE DRIVER, GREELEY, BOXCAR, BENHAM, JORUM, HANDLEY) and two on Amchitka Island (MILROW and CANNIKIN). The stars indicate the shot locations and the dots show the distribution of seismograph stations used in magnitude calculations.

Similar findings of the difference between east and west coast magnitude values have been reported by Solomon and Toksoz (1970) and Nuttli (1973) and attributed by them and others (Ward and Toksoz, 1971; Jordan and others, 1965) to be mostly due to lateral variations in the crust and upper mantle.

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